

METALLURGIA

THE BRITISH JOURNAL OF METALS

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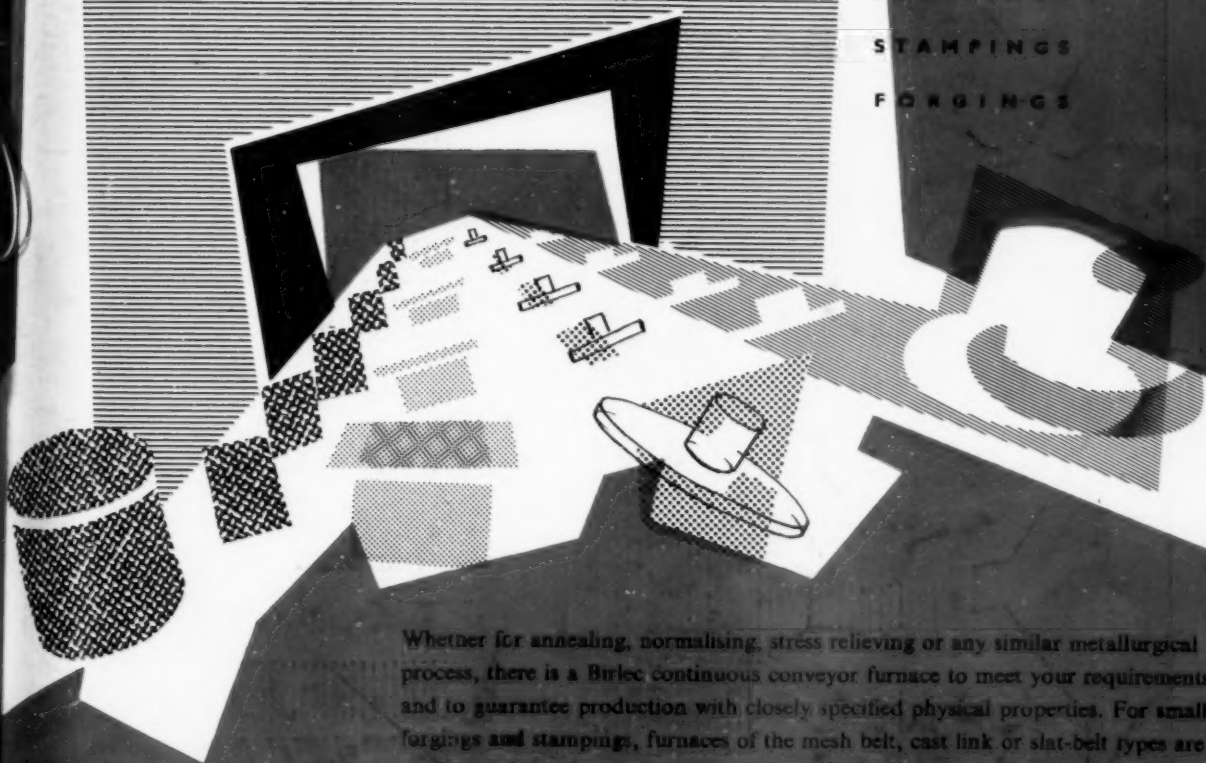
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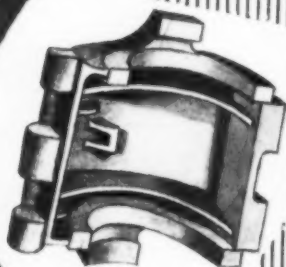
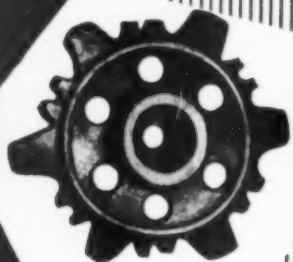
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METALLURGIA

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INCORPORATING THE METALLURGICAL ENGINEER

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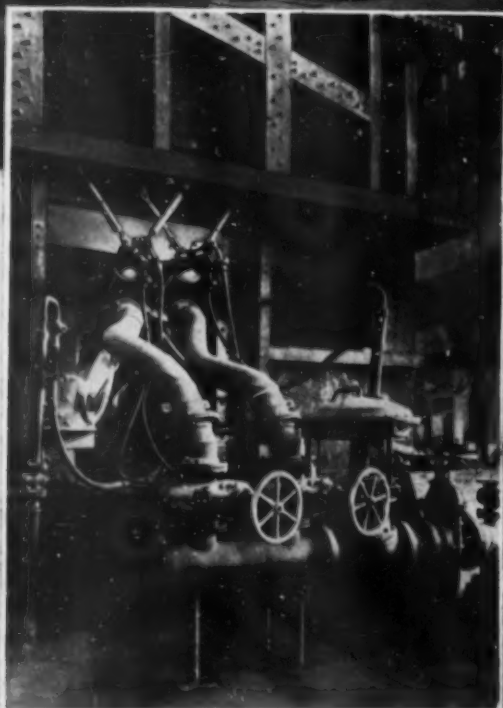
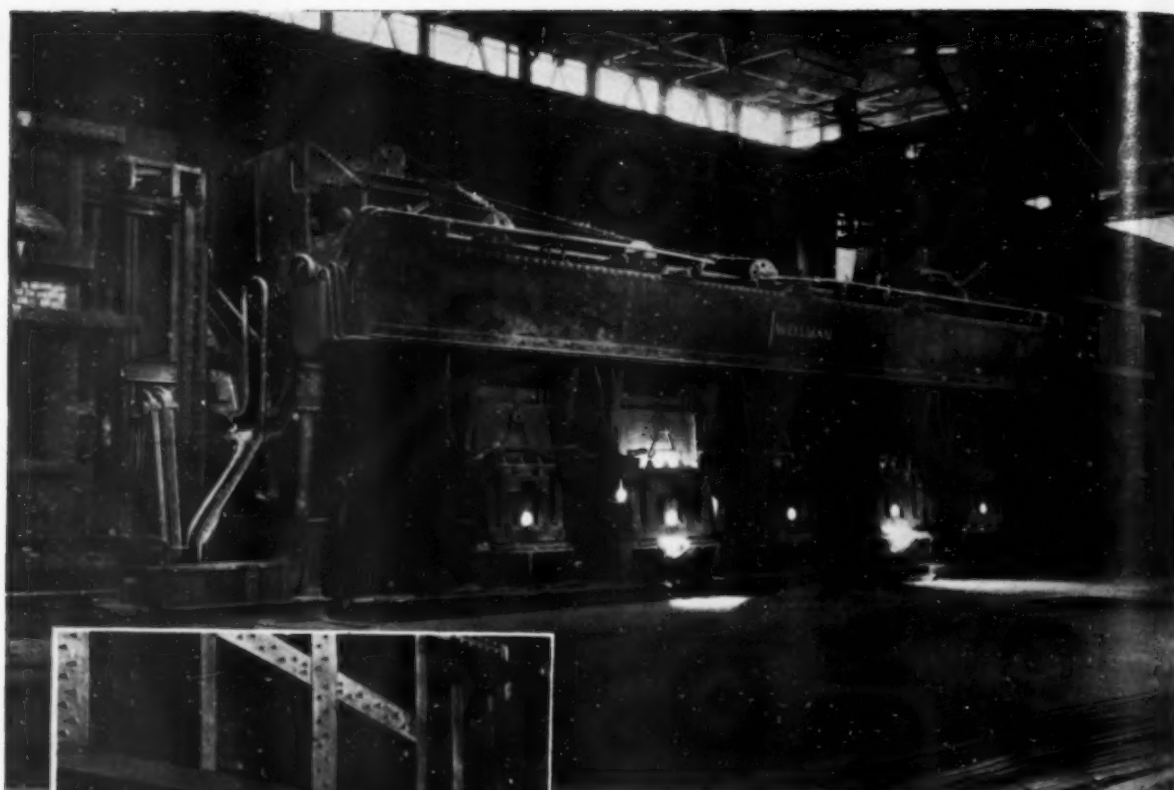
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METALLURGIA

THE BRITISH JOURNAL OF METALS
INCORPORATING THE "METALLURGICAL ENGINEER"

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Public Ownership

AT the recent Labour Party Conference at Brighton, there appeared to be an increasing awareness that if the party is to succeed in regaining control of the House of Commons at the next election, it will have to adopt a policy which is not only acceptable to the various shades of opinion within the party itself, but also to the marginal voters who hold allegiance to neither of the main political parties. There was a realisation that the extreme left wing insistence on more nationalisation, whether desirable or not, would lead to the alienation of many thinking men and women in the electorate who are far from satisfied with the performance of the Conservatives in office, and who might, therefore, tilt the scales in favour of the Socialists.

In the policy statement, various aspects of which were discussed at length at Brighton, the Socialist planners advocate a technique of gaining control of key industries by the acquisition of shares in them, the impression being given that in this way the wicked capitalists will be deprived of their power to flourish at the expense of the working man. But who are these capitalists? As an industry which it is still the avowed intention of the Socialists to renationalise; the steel industry has provided some interesting information on this very point.

In an article in the October, 1957, issue of *Steel Review* bearing the heading "Who owns the Steel Industry," which has also been published as a separate leaflet by the British Iron and Steel Federation, it is pointed out that the steel industry has a dual accountability. It is accountable to the nation, through the Iron and Steel Board, for major policy decisions affecting the national interest; and it is accountable to its shareholders for the efficient use of its assets. The powers and activities of the Board have been well publicised, but not much information has hitherto been available concerning the industry's new owners. With a view to remedying this defect, the Federation has collected information concerning the distribution of shareholdings in the steel companies which have been denationalised. The figures relate to the ordinary shares of eleven firms with an aggregate par value of £101 million, and accounting for 68% of the total crude steel output of privately owned companies in 1956. The Steel Company of Wales was excluded because the details were not available at the time of preparing the article, it having only recently been re-sold, and a number of other firms were not considered because they are part of larger groups having wide interests outside the steel industry.

The idea that the steel industry is privately owned in the sense that private companies often are, having only a few shareholders, is rapidly dispelled by a glance at the number of ordinary shareholders in all these eleven firms. In only two is the figure less than 10,000 and in four it exceeds 25,000; indeed, half the companies analysed

have more shareholders than employees. Nor is it a case of a large number of shareholders with tiny holdings and one or two holding the bulk of the shares. Taking a weighted average of the eleven companies, 40% of the shareholders hold not more than £100 worth each (nominal value), and a further 50% hold between £100 and £500 worth each. Furthermore, one third of the capital, speaking broadly, is owned by shareholders owning less than 500 shares each, and another third by those owning between 500 and 10,000 shares. The big shareholders thus own only one third of the total shareholding.

A further study of the large shareholders discloses the fact that the small investors total stake in the steel industry is actually much larger than is indicated by the figures given above, since a number of institutions, such as insurance companies, pension funds and investment trusts, which have considerable shareholdings in steel companies, rely for their finance (insurance premiums, pensions contributions, etc.) mainly on persons of moderate means. Allowing for these "indirect" investments, the ownership of steel companies is seen to be even more widely spread than would appear at first sight.

The large investors, even in aggregate, do not therefore dominate the ownership of steel companies, and a more detailed analysis of the ten largest shareholders for each of eight companies with a crude steel output of over 10 million tons in 1956, shows their aggregate shareholding to vary from 8% in the case of Colvilles to 19.1% in the case of Whiteheads. Insurance companies are the largest single group in five of them, and figure prominently in all.

In a number of steel companies, employees have been encouraged to acquire shares in the company employing them. At Colvilles, for instance, at the time of the re-sale in 1955, arrangements were made for the cost of purchase of shares to be deducted from wages over a period of two years, and in this way, 1,200 applications were received for 105,000 shares. In some cases shares in the company are owned by employees indirectly, as, for instance, Consett, where the 25,395 shares owned by employees include 10,000 held by the company's pension fund. Incidentally, in April, 1957, the Mineworkers' Pension Scheme and the National Insurance (Industrial Injuries) Colliery Workers' Supplementary scheme, owned over 700,000 preference and ordinary shares in iron and steel companies.

The essence of the findings of the enquiry are that no individuals or groups are dominant in the ownership of the large denationalised steel companies, but that the equity of these companies is widely distributed among a large number of mainly small or medium sized investors. The present organisation of the industry, with centralised control, decentralised management and widespread ownership has evolved slowly—it would be a disservice to subject it to the shock of nationalisation again.

Meeting Diary

5th November

Sheffield Metallurgical Association. "Schematic Methods of Metallurgical Analysis," by D. F. SERMIN. B.I.S.R.A., Hoyle Street, Sheffield. 7 p.m.

6th November

Institute of Welding, Manchester and District Branch. "Ultrasonic Testing of Welds," by J. JOHNSON. Reynolds Hall, College of Science and Technology, Manchester. 7.15 p.m.

Institution of Production Engineers, Nottingham Section. "Manufacture of Tubing," by a REPRESENTATIVE of the YORKSHIRE COPPER WORKS, LTD., Leeds. Illustrated by a film. The Victoria Station Hotel, Nottingham. 7 p.m.

Manchester Metallurgical Society. "Weldable High Strength Steels," by DR. K. J. IRVINE. Manchester Room, Central Library, Manchester. 6.30 p.m.

7th November

East Midlands Metallurgical Society. "Rare Metals," by DR. J. C. CHASTON. Nottingham and District Technical College, Shakespeare Street, Nottingham. 7.30 p.m.

Institute of Metals, Birmingham Local Section. "Tool Steel Development," by A. P. T. TAYLOR GILL. College of Technology, Gosta Green, Birmingham. 6.30 p.m.

Institute of Metals, London Local Section. "Refractories," by DR. J. WHITE. Royal School of Mines, South Kensington, London, S.W.7. 7 p.m.

Institution of Production Engineers, Leicester Section. "Fusion Welding of Ferrous Materials" by P. H. R. LANE. The Schofield Building, Loughborough Technical College. 7 p.m.

Leeds Metallurgical Society. "The Development of Electronics for Process Control and Inspection," by C. H. GOULD. Yorkshire Copper Works, Ltd., Leeds. 7.15 p.m.

8th November

Institution of Mechanical Engineers in conjunction with the British Nuclear Energy Conference. "Vacuum Techniques in the Atomic Energy Industry," by DR. H. KRONBERGER. O.B.E. 1, Birdage Walk, London, S.W.1. 5.30 p.m. for 6 p.m.

11th November

Institute of Metals, Scottish Local Section. "Vacuum Metallurgy," by DR. IAN F. C. WEIL. Institution of Engineers and Shipbuilders in Scotland, 39, Elmbank Crescent, Glasgow, C.2. 6.30 p.m.

Institution of Structural Engineers, Lancashire and Cheshire Branch. "Steel Tubes and Hollow Sections," by G. B. GODFREY. College of Science and Technology, Manchester. 6.30 p.m.

12th November

Incorporated Plant Engineers, Manchester Branch. "Nuclear Power," by a LECTURER from the UNITED KINGDOM ATOMIC ENERGY AUTHORITY. Joint meeting with the **Institution of Heating and Ventilating Engineers.** Engineers' Club, Albert Square, Manchester. 7.15 p.m.

Institute of British Foundrymen, Slough Section. Afternoon Works Visit to Trucast, Ltd., Farnham Royal Lodge, Slough. Evening meeting, also at Trucast—"Precision Investment Casting compared with other Foundry Processes," by L. N. SMITH and L. N. HOCKING.

Institute of Metals, Oxford Local Section. "Recent Advances in Iron-Making," by a MEMBER of the STAFF of the BRITISH IRON and STEEL RESEARCH ASSOCIATION. Cadena Cafe, Cornmarket Street, Oxford. 7 p.m.

Institute of Metals, South Wales Local Section. "Nuclear Power," by L. ROTHERHAM. The Royal Institution, Swansea. 7 p.m.

Sheffield Metallurgical Association. "Some Metallurgical Problems in the Production of Cast Steels," by W. J. JACKSON. B.I.S.R.A., Hoyle Street, Sheffield. 7 p.m.

13th November

Incorporated Plant Engineers, Western Branch. "Some Aspects of Flue Gas Corrosion," by P. F. CORBETT. Grand Hotel, Bristol. 7.15 p.m.

Liverpool Metallurgical Society. "Application of Inert Gas Electric Arc Welding," by P. J. L. LEDER. Joint Meeting with the **Liverpool Branch of the Institute of Welding.** Picton Library. 7 p.m.

Manchester Statistical Society. "The Steel Industry," by E. T. SARA. Reform Club, King Street, Manchester. 5.30 p.m.

14th November

Incorporated Plant Engineers, North-East Branch. "Steel Production by Modern Methods," by G. E. HEMMING. Roadway House, Oxford Street, Newcastle upon Tyne. 7 p.m.

North East Metallurgical Society. "Fatigue," by DR. N. THOMPSON. Cleveland Scientific and Technical Institution, Corporation Road, Middlesbrough. 7.15 p.m.

15th November

Incorporated Plant Engineers, Birmingham Branch. "Planned Maintenance in Foundries," by E. S. KING. Hotel Leofrie, Coventry. 7.30 p.m.

Institute of Physics, Industrial Spectroscopy Group. "Spectroscopy in the United Kingdom Atomic Energy Authority." All-day meeting at the Institute's House. 47 Belgrave Square, London, S.W.1.

Institution of Mechanical Engineers. Thomas Hawksley Lecture: "Vibration," by PROF. J. P. DEN HARTOG. 1 Birdcage Walk, London, S.W.1. 5.30 p.m. for 6 p.m.

West of Scotland Iron and Steel Institute. "Work Study in the Iron and Steel Works," by P. HANIK and E. GLEN. 39 Elmbank Crescent, Glasgow. 6.45 p.m.

19th November

Institute of British Foundrymen, East Anglian Section. "Effect of Moulding Methods on the Physical Properties of Sand Moulds," by W. B. PARKES. Lecture Hall, Public Library, Ipswich. 7.30 p.m.

Institution of Chemical Engineers, North Western Branch. Symposium on Pressure Vessels. College of Science and Technology, Manchester. 6.30 p.m.

Sheffield Metallurgical Association. "The Production and Properties of Cemented Carbides and Ceramic-Metal Combinations," by DR. E. M. TRENT. B.I.S.R.A., Hoyle Street, Sheffield. 7 p.m.

20th November

Birmingham College of Technology Metallurgical Society. "Oils and the Metallurgist," by H. A. SNOW. College of Technology, Birmingham. 6.30 p.m.

Institute of British Foundrymen, London Branch. "Safety in the Foundry," by H. P. MILLAR. Constitutional Club, Northumberland Avenue, London, W.C.2. 7.30 p.m.

Manchester Metallurgical Society. "Metallurgical Education," by PROF. G. V. RAYNOR. Manchester Room, Central Library, Manchester. 6.30 p.m.

Society of Chemical Industry, Corrosion Group. "Protection of Magnesium Alloys," by W. F. HIGGINS. 14 Belgrave Square, London, S.W.1. 6.30 p.m.

21st November

Institute of Metals, Birmingham Local Section. "Metallurgical Thermodynamics," by DR. J. N. PRATT. Birmingham Exchange and Engineering Centre, Stephenson Place, Birmingham. 6.30 p.m.

25th November

Incorporated Plant Engineers, West and East Yorkshire Branch. "Nuclear Reactors for Power Production," by J. A. DIXON. Leeds University. 7.30 p.m.

26th November

Sheffield Metallurgical Association. "The Habershon Planetary Mill," a film dealing with installation, operation and practical experience. Introduction by R. D. R. HABERSHON; the discussion replied to by H. W. WARD assisted by the mechanical and electrical engineers concerned. B.I.S.R.A., Hoyle Street, Sheffield. 7 p.m.

27th November

North East Metallurgical Society. Visit by the President of the Institution of Metallurgists. (Venue to be arranged).

(Continued on page 241)

The Extraction of Minor Phases from Austenitic Steel

By J. F. Brown, Ph.D., W. D. Clark, M.A., M.Sc., and A. Parker, B.A.

Imperial Chemical Industries, Ltd., Billingham Division.

Electrolytic solution has been used by various investigators as a means of concentrating minor phases in complex alloys. The various solutions used are discussed and attention is also given to the design of the cell. Results on a variety of austenitic steels extracted with six electrolytes are given and the preferred procedure selected. A series of 18/8/Ti and 18/8/Nb steels was then examined to find the effect of heating at 500–900° C., for up to 500 hours on the phases present. It is shown that chromium carbide is found in all these steels, but with longer times of heating is replaced by sigma.

Relevant data on corrosion rates are also given.

FOR very many years a primary objective of the physical metallurgist has been to relate the properties of alloys to the phases present, and the effect of heat treatment to the equilibrium phase diagram. The original techniques used—optical microscopy and thermal analysis—have become increasingly inadequate to deal with alloys developed by empirical methods which contain five or more elements in important amounts and, as in the case of steels, several others (e.g. N, Al, S, P, Cu, Mo) in quantities which it is not entirely safe to neglect. While important new weapons, such as X-ray techniques and the electron microscope, have been added to his armoury, these have severe limitations: powder photographs will not show any phase present occupying less than 2% of the metal (and if the crystal structure is characterised by a multiplicity of weak X-ray reflections, the figure is more like 10%), and the electron microscope all too often gives clear pictures of particles which cannot be identified.

In the last few years several investigators (refs. 1-7 are typical) have supplied a technique which must be considered a development of the methods used for the isolation of the non-metallic inclusions in iron and steel.^{8,9} The principle is to remove the major phases present by an agent which leaves the minor phases untouched, and the result is that the minor phases can be concentrated and examined by X-ray and other techniques with a much greater hope of making positive identifications. In the work on non-metallic inclusions, the bulk of the sample was vaporised in chlorine⁸ or dissolved in alcoholic iodine⁹: in the more recent work on austenitic steels, the usual procedure has been to attack the specimen anodically in an aqueous electrolyte. For reasons shown below, this gives greater opportunities of controlling the extraction process.

The method is, of course, open to a number of serious objections. It produces a concentrate of some of the minor phases present in the alloy, but residual amounts of the major phases may be present. If the alloy contains minor phases which are attacked under the extraction conditions, there is no way of determining this unless they have already been detected in the bulk alloy. The relative quantities of phases in the concentrate bear an unknown relation to those in the alloy, and it is possible for the concentrate to contain phases not present in the alloy. This latter effect is probably uncommon, but Hoar and Bowen¹ showed that a steel

containing no ferrite gave a concentrate containing some ferrite, apparently as a result of breakdown of austenite following the release of tessellated stresses. Even so, the method can give information not obtainable by any other means.

Examination of the literature shows that many different techniques have been used, and all too often little or no detail is given of the procedure. The first part of this paper covers a comparison of six different methods with the object of finding the best technique for austenitic steels. The second part describes the results obtained on various stabilised austenitic steels.

PART I—DEVELOPMENT OF A PREFERRED TECHNIQUE

Mechanism and Factors Affecting the Extraction Process

When a metal is made anodic in an electrolyte, it will either dissolve according to Faraday's laws, or go passive through the production of a resistant film on its surface, from which oxygen may be evolved. In general, the tendency to become passive will increase with the current density, and will be highest with alloys rich in elements such as chromium and silicon. In an alloy containing several phases, it may be possible to select a combination of electrolyte, current density, and temperature which will attack some phases while leaving others passive: the particles of the passive phases will fall away as the other phases dissolve. The fundamental variable is not in fact the current density, but the potential of the metal relative to the solution, which bears a complex relation to the current density; in practice, however, the current has been controlled rather than the potential.

It must be kept in mind that once the particles become separated from the bulk sample they are no longer maintained at a passive potential, and may suffer normal corrosion by the electrolyte. It is desirable, therefore, to remove them from the electrolyte as soon as possible after separation.

Since at the cathode metal may be electrodeposited from the solution, it is necessary to ensure that no detached particles of cathode deposit become mixed with the concentrate. Again, since the electrolysis affects the composition of the electrolyte and may thus affect the passivity of certain phases, it is desirable to

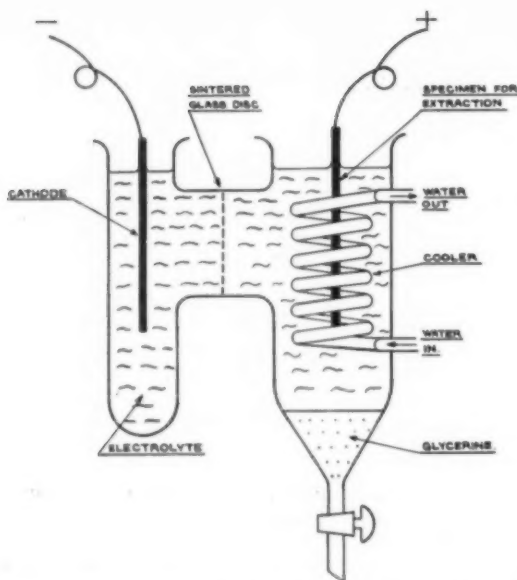


Fig. 1.—Water-cooled cell with sintered glass partition.

renew the electrolyte continuously, or at least to circulate or agitate it.

According to the spacing of the electrodes, the current passed, and the nature of the electrolyte, a considerable amount of heat may be generated in the cell. Unless the temperature is maintained constant, the passivity of the phases to be preserved may be affected. It is, therefore, desirable to include means of cooling the electrolyte.

Design of Extraction Cell

The early workers in the field used the simplest possible cell. Hoar and Bowen¹ took steps to improve the procedure. They eliminated contamination from the cathode by enclosing it in a canvas bag, maintained the area of the specimen being attacked constant by periodic adjustments of the electrolyte level, and had a layer of glycerine in the bottom of the cell into which the concentrate sank (the glycerine would largely prevent any direct corrosion of the separated particles).

Various different designs of cell were tried in the present work. Much use was made of that shown in Fig. 1. A sintered glass disc separated the anode and cathode compartments, and the anode compartment was water cooled. While this cell was fairly satisfactory in use, it had certain faults. The resistance was high—

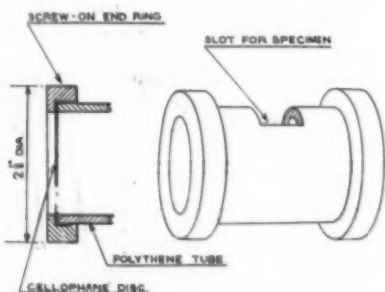


Fig. 2.—Polythene anode compartment with cellophane membranes.

about 100 ohms—and at moderate current densities the cooling coil was unable to cope with the heat developed. The volume of anolyte was small, it was not circulated (apart from convection), and its composition would change during use. Most important, the attack on the specimen was not uniform, and hence the conditions of extraction were probably seriously different on the two faces of the specimen. A modification of this cell to overcome this last point was made by using two sintered glass discs, one facing each surface of the specimen, with additional cathode area, but this arrangement was discarded in favour of that shown in Figs. 2 and 3, which is now preferred.

It was found that thin cellophane made an excellent membrane, which had a low resistance and was not attacked by the electrolytes used. Two discs of cellophane about 0.02 mm. thick were supported in the polythene anode compartment shown in Fig. 2: this unit was incorporated in the arrangement shown in Fig. 3. The electrolyte is taken from the anode compartment, pumped through a cooler and returned. The specimen sits through a slot in the top of the polythene tube. This slot is above the liquor level and there is thus no possibility of cathode deposits circumventing the membranes. The resistance is only about 10 ohms, and the cooling is adequate to maintain a constant 25° C. with 10 amp. passing. Attack on the anode is uniform.

One complication of a circulating arrangement is that it is less easy to arrange for the concentrate to settle into a protective glycerine layer, and glycerine was not used in the apparatus of Fig. 3. The effect of continual exposure to the electrolyte has not been examined. It is possible that some phases present in the metal which are passive during electrolysis are seriously attacked when they have been detached. This depends on the activity of the electrolyte as a corrodant and the composition of the phase.

Tests with Three Steels Using Six Procedures

It was decided to compare the results obtained from a number of austenitic steels, using six representative

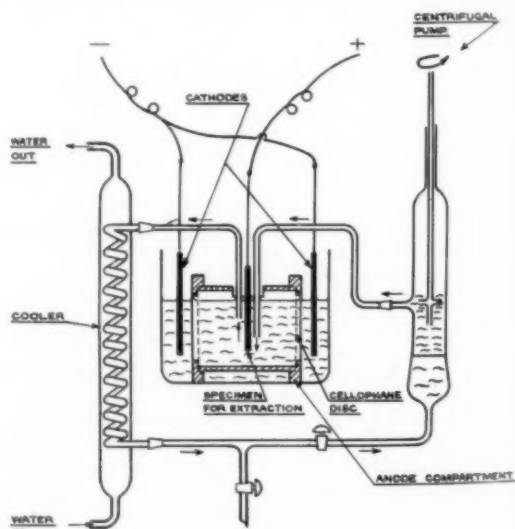


Fig. 3.—Complete apparatus using polythene cell with cellophane membranes.

TABLE I.—COMPOSITION OF STEELS EXAMINED.

Type of Steel	Code	Heat Treatment	Composition (%)							
			C	Cr	Ni	Si	Mn	Mo	Ti	S
18/8	E	$\frac{1}{2}$ hr. 1,150° C., WQ	0.12	18.3	8.14	0.82	0.37	—	—	0.02
18/8/Ti	G1	$\frac{1}{2}$ hr. 1,150° C., WQ	0.12	18.4	8.01	0.63	0.47	0.12	0.72	0.016
	G2	$\frac{1}{2}$ hr. 1,350° C., WQ + 2 hr. 650° C., WQ ..								
18/8/Mo/Ti	F1	$\frac{1}{2}$ hr. 1,150° C., WQ	0.07	19.2	8.54	0.56	0.86	3.25	0.32	0.032
	F2	$\frac{1}{2}$ hr. 1,150° C., WQ + 4 hr. 850° C., WQ ..								0.029

combinations of electrolyte and current density. The steels chosen were a softened 18/8, expected to contain very little in the way of minor phases, an 18/8/Ti in the softened condition and also after a heat treatment known to reduce its corrosion resistance to nitric acid, and an 18/8/Mo/Ti in the softened condition and also after a heat treatment which would produce some *sigma*-phase. Details of analysis and heat treatment are shown in Table I.

Most of the extractions were carried out in a cell of the type shown in Fig. 1, but successive improvements were made during the course of the work, and the apparatus of Fig. 3 became standard. The current was maintained constant, but control of cell temperature was, in general, not good when the heat liberated in the cell was high. The six conditions of electrolysis are shown in Table II.

Electrolytes 1 and 2 are similar to those used by Hoar and Bowen¹, who found with 18/8/Mo/Ti that at low current densities austenite and martensite were present in the concentrate, but as the current was increased the proportion of *sigma* in the concentrate increased. No. 3 was a combination which it was hoped would be less corrosive to the separated phases than were 1 and 2. No. 4 has been previously reported to attack ferrite and *sigma* and leave austenite. Nos. 5 and 6 are strong oxidising agents which are of use for selective etching of this class of steel.

The procedure was to cut specimens $2 \times 1 \times \frac{1}{8}$ in. from plates of each steel, heat treat and then pickle. The pickled specimens were then examined by the standard X-ray reflection technique to establish the phases detectable by this normal procedure. Each sample was weighed and then introduced into the cell, a known area being immersed, the appropriate current applied, and anodic attack continued for a suitable time. The sample was then removed, adherent particles detached with a nylon brush, and reweighed. The concentrate (together with the material brushed from the specimen) was recovered from the electrolyte by centrifuging, washed, dried and weighed. The percentage extraction, i.e. weight of concentrate over loss in weight of specimen, was calculated and also the anode efficiency, i.e. weight of specimen dissolved per amp. hr. passed. The concentrate was then examined by the X-ray powder technique in a 9 cm. diameter camera with a Van Arkel type film mounting using Co-K α radiation. It was also examined in an X-ray spectrometer of the emission type, to determine the elements present and, roughly, their relative concentrations.

Results

Tables III—VII show for each type of specimen the results achieved by each of the electrolytic procedures, and detail the weight of extract collected, the percentage extraction, the phases recognised in the extracts by interpretation of the powder photographs, the spacings

corresponding to lines not accounted for by recognised phases, the X-ray emission spectrometer measurements, and whether or not the extract was ferromagnetic.

Phases Identified

Appendix I lists the characteristic spacings by which the various phases likely to be present in the extracts are normally identified. A number of extracts gave rise to lines on the powder photographs which could not be ascribed to any of the phases which might be expected to be present. Some of these lines have been tentatively identified as due to oxides of the Fe₂O₃ or Fe₃O₄ types. One combination of lines appeared many times and has been ascribed to a phase termed *tau* (τ), the nature of which is discussed later (part II): the relevant lines are listed in Appendix I.

The phases TiC and TiN are similar in structure and known to form solid solutions. In some extracts they could be identified separately by their lattice parameters (cube edges: TiC = 4.320 Å; TiN = 4.235 Å) but in others an intermediate cube edge—4.27 Å was noted.

The appearance of Cr₂₃C₆ in steel G is dealt with more fully in the second section of this paper.

Comparison of Electrolytes

The main purpose of this part of the work was to compare the six electrolytic procedures listed in Table II. A simple way of doing this was to check how many of the minor constituents in the five types of specimen were preserved by each. Table VIII lists the phases considered, and, in the first line, in how many of the five types of specimen each phase has been preserved by one or more of the procedures. The other lines show the performance of each procedure. It may be noted that preservation of *alpha* or *gamma* is, in general, undesired, as liable to "dilute" the extract and possibly hide small quantities of, for example, Cr₂₃C₆.

Table VIII shows procedure 3 to be most generally satisfactory. This evidence is not entirely fair, in that the same type of cell was not used in all cases, and this may effect the results, especially in those baths which have a high resistance. Procedure 3, however, recovers all the phases desired with the exception once of TiN; later work (Section II) showed that a cell of the type of

TABLE II.—EXTRACTION CONDITIONS

Code	Electrolyte	Normal Current Density (amp./sq. cm.)	Operating Temperature (° C.)	Anode Efficiency (g./amp.hr.)
1	5% w/v HCl in water ..	0.08	12-18	0.37/0.92
2	20% w/v HCl in water ..	4.7	40-80	0.70/1.0
3	10% v/v of 35% aqueous HCl in ethyl alcohol ..	0.08	30-50	0.78/0.96
4	10% w/v H ₂ SO ₄ in water ..	0.08	12-19	0.23/0.57
5	10% w/v CrO ₃ in water ..	0.08	12-20	0.19/0.45
6	10% w/v CrO ₃ in water ..	1.1	20-90	0.24/0.47

TABLE III.—STEEL E, 18/8 Cr/Ni, CONDITION 1,150° C., WQ.
(Phases observed in solid specimen: *gamma* + trace *alpha* (probably martensite))

Procedure		1	2	3	4	5	6	
Electrolyte		5% HCl aq.	20% HCl aq.	10% HCl alc.	10% H ₂ SO ₄ aq.	10% CrO ₃ aq.	10% CrO ₃ aq.	
Current Density (amp./sq. cm.)		0.08	4.7	0.08	0.08	0.08	1.1	
Anode Efficiency (g./amp. hr.)		0.90	0.92	0.89	0.23	0.19	0.24	
Extraction (%)		0.7	1.8	0.6	0.04	0.65	0.3	
Weight of Extract (mg.)		26	101	15	0.7	9.5	4	
Powder Photo of Extract	Phases	<i>Gamma</i> (m)	—	—	Fe ₃ O ₄ <i>Alpha</i> — Fe ₂ O ₃	—	—	
	Extra Lines (Å)	2.58 (w) 1.82 (vw) 1.05 (vvw)	2.69 (w) 2.51 (w) 1.69 (vw) 1.47 (vw)	2.71 (vw) 2.55 (m) 2.22 (vvw) 1.77 (vw) 1.70 (vw) 1.50 (vw) 1.47 (vvw)	3.34 (vvw) 2.41 (vvw) 2.28 (vvw) 2.03 (vvw)	—	2.43 (w) 1.70 (vw) 1.41 (w)	
	X-ray Spectrogram	Major Minor Trace	Cr, Fe Si Ti, Mn	Si — Fe, Ni, Cr	Si Cr Ti, Mn	Fe, Cr Ti Si, Mn	Cr Mn Ti, Si	Mn Fe —
	Magnetic Properties		Trace	Nil	Nil	Fairly strong	Trace	Nil

* a, m, w, vw, vvw—strong, medium, weak, very weak, very very weak.

TABLE IV.—STEEL G1, 18/8/Ti, CONDITION 1,150° C., WQ.
(Phases observed in solid specimen: *gamma*, *alpha*, TiC)

Procedure	1	2	3	4	5	6	
Electrolyte	5% HCl aq.	20% HCl aq.	10% HCl alc.	10% H ₂ SO ₄ aq.	10% CrO ₃ aq.	10% CrO ₃ aq.	
Current Density (amp./sq. cm.)	0.08	4.7	0.08	0.08	0.08	1.1	
Anode Efficiency (g./amp. hr.)	0.92	0.85	0.89	0.24	0.20	0.34	
Extraction (%)	0.9	1.1	1.2	0.3	1.1	0.7	
Weight of Extract (mg.)	44	55	54	5	15	14	
Powder Photo of Extract	Phases	<i>Alpha</i> (m) TiC (mw) <i>Gamma</i> (vw) <i>Tau</i> ?	TiC (m) TiN (vvw) <i>Tau</i> (vw) ?	TiC (s) TiN ? <i>Tau</i> (w)	TiC (m) TiN (w) <i>Alpha</i> (vw)	TiC (m) TiN (vw) Cr (vw)	TiC (ms) <i>Alpha</i> (m) <i>Gamma</i> (w) TiN (vw)
	Extra Lines (Å)	—	—	—	1.47 (vw)	—	—
X-ray Spectrogram	Major Minor Trace	Fe, Ti Cr, Si —	Ti Si —	Ti Cr, Fe Ni, Mn	Cr, Ti — Fe, Mn, Ni	Ti Fe, Cr, Mn —	
Magnetic Properties	Strong	Nil	Nil	Trace	Slight	Moderate	

TABLE V.—STEEL G2, 18/8/Ti, CONDITION 1,350° C., WQ + 2 hr. 650° C., WQ.
(Phases observed in solid specimen: *gamma*, *alpha*)

Procedure	1	2	3	4	5	6	
Electrolyte	5% HCl aq.	20% HCl aq.	10% HCl alc.	10% H ₂ SO ₄ aq.	10% CrO ₃ aq.	10% CrO ₃ aq.	
Current Density (amp./sq. cm.)	0.08	4.7	0.08	0.08	0.08	1.1	
Anode Efficiency (g./amp. hr.)	0.9	1.0	0.96	0.54	0.52	0.36	
Extraction (%)	3.7	3.1	1.1	21.6	22.6	8.6	
Weight of Extract (mg.)	226	193	43	1030	907	202	
Powder Photo of Extract	Phases	<i>Alpha</i> (s) <i>Gamma</i> (mw) TiC (w) <i>Tau</i> ? (vw) (Cr ₂ N ₃ ? (vw)	<i>Gamma</i> (m) <i>Alpha</i> (w) TiC (vw) <i>Tau</i> ? (vw)	Cr ₂ N ₃ (m) TiC (m) <i>Tau</i> ?	<i>Gamma</i> (s) <i>Alpha</i> (m)	<i>Gamma</i> (s) <i>Alpha</i> (ms) TiC (vvw)	<i>Alpha</i> (s) <i>Gamma</i> (m) TiC (vvw)
	Extra Lines (Å)	1.97 (vvw)	—	2.08 (vvw) 0.949 (vvw)			
X-ray Spectrogram	Major Minor Trace	Cr, Fe, Ti Ni —	Fe Cr, Ti —	Ti Cr, Fe Ni, Si	Fe, Cr Ti Ni, Mn	Fe Cr Si, Ti	
Magnetic Properties	Strong	Moderate	Nil	Strong	Strong	Strong	

Fig. 3 would recover TiN consistently. It is therefore preferred to the others.

Discussion of Phases Found

These preliminary experiments showed a number of items worthy of comment.

- (1) *Steel E* (18/8—as softened).—Table III shows that a considerable residue was collected with procedure 2, but that it contained no identifiable phases. It was rich in silicon.
- (2) *Steel G1* (18/8/Ti—as softened).—All the extracts contained TiC of normal lattice parameter. Only

the hydrochloric acid extracts showed *tau*. Hoar and Bowen¹ found that, in hydrochloric acid baths, increase in the current density caused a decrease in the amount of *alpha* or *gamma* preserved, and the same feature was found here. With the CrO₃ electrolyte, however, increase in current density increased the amount of *alpha* and *gamma* preserved.

- (3) *Steel G2* (18/8/Ti—as sensitized).—Micrographically this steel contained large areas of ferrite formed at 1,350° C., which, during re-heating at 650° C., had broken down to a complex containing finely divided austenite and ferrite. The per-

TABLE VI.—STEEL F1, 18/8/3 Mo/Ti, CONDITION 1,150° C., WQ.
(Phases observed in solid specimen: *gamma*, *alpha*)

Procedure	1	2	3	4	5	6
Electrolyte	5% HCl aq.	20% HCl aq.	10% HCl alc.	10% H ₂ SO ₄ aq.	10% CrO ₃ aq.	10% CrO ₃ aq.
Current Density (amp./sq. cm.)	0.08	4.7	0.08	0.08	0.08	1.1
Anode Efficiency (g./amp. hr.)	0.57	0.88	0.83	0.25	0.23	0.32
Extraction (%)	0.1	0.4	2.1	0.4	0.4	1.0
Weight of Extract (mg.)	4	33	91	7	6	22
Powder Photo of Extract	Phases	<i>Alpha</i> (w) <i>Gamma</i> Fe ₃ O ₄ ?	TiN (m) <i>Gamma</i> (vww) <i>Tau</i> (m)	<i>Alpha</i> (s) TiN (w) <i>Tau</i> (w)	TiN (m) <i>Alpha</i> (mw) <i>Gamma</i> (vw) <i>Gamma</i> Fe ₃ O ₄ ?	<i>Gamma</i> (s) TiN (w) <i>Tau</i> ?
	Extra Lines (Å)	3.64 (vw) 2.67 (mw) 1.81 (vw) 1.75 (vw) 1.67 (w) 1.24 (vww) 1.09 (vww) 1.06 (vww)	3.53 (vw) 3.09 (vw) 2.96 (vw) 2.67 (vw) 1.67 (vww) 1.47 (vw) 0.98 (vww)		1.67 (vw)	
X-ray Spectrogram	Major Minor Trace		Ti Fe, Cr, Si	Fe, Cr, Ti Fe Si, Ni	Cr, Ti Fe Si	Ti, Cr Fe Si
Magnetic Properties	Moderate	In part	Strong	Moderate	Strong	Nil

TABLE VII.—STEEL F2, 18/8/Mo/Ti, CONDITION 1,150° C. WQ + 850° C. WQ.
(Phases observed in solid specimen: *gamma*, *alpha*, *sigma*.)

Procedure	1	2	3	4	5	6
Electrolyte	5% HCl aq.	20% HCl aq.	10% HCl alc.	10% H ₂ SO ₄ aq.	10% CrO ₃ aq.	10% CrO ₃ aq.
Current Density (amp./sq. cm.)	0.08	4.7	0.08	0.08	0.08	1.1
Anode Efficiency (g./amp. hr.)	0.83	0.7	0.78	0.57	0.55	0.47
Extraction (%)	14.6	3.2	7.4	6.1	6.6	4.8
Weight of Extract (mg.)	1,064	208	323	261	233	121
Powder Photo of Extract	Phases	<i>Alpha</i> (w) <i>Sigma</i> (mw) <i>Tau</i> ?	<i>Chi</i> (s) <i>Sigma</i> (m)	<i>Chi</i> (s) <i>Sigma</i> (ms)	<i>Gamma</i> (vs) TiN (vww) <i>Alpha</i> (vww)	<i>Gamma</i> (s) <i>Alpha</i> (vww) TiN (vww)
	Extra Lines (Å)	1.01 (vw)		2.16 (ww) 1.47 (vww)		
X-ray Spectrogram	Major Minor Trace	Cr, Fe	Fe, Cr Ti Ni	Fe, Cr Ti Ni	Fe, Cr Ti Ni, Mn	Fe Ni, Ti Mn Si
Magnetic Properties	Strong	Nil	Nil	Slight	Slight	Very Slight

tage extraction was much higher than with G1, and all extracts (except from bath 3) contained both *gamma* and *alpha*. Very possibly this results from detachment from the decomposing ferrite of particles containing both *alpha* and *gamma*. Chromium carbide is clearly shown only by bath 3. Possibly in the other extracts it was present but hidden by the amount of *alpha* and *gamma* present. The same reason may explain the non-appearance of TiN. "TiC" was present in five of the extracts, but had a low cube edge ranging towards that of TiN (4.24–4.27 Å), whereas in G1 the cube edge was normal (4.32 Å). This observation shows that the state of combination of the titanium can be affected by heat treatment at, e.g. 1,350° C.

- (4) *Steel F1 (18/8/Mo/Ti—as softened)*.—In no case was TiC recovered with this steel, but TiN was found in five extracts, and the unknown phase *tau* also appeared three times.
- (5) *Steel F2 (18/8/Mo/Ti—as reheated)*.—These specimens had been treated at 850° C. to produce some *sigma*. Only baths 1, 2, and 3 recovered *sigma*. It was unexpected to find *chi* (χ) prominent with baths 2 and 3. This phase is well known in complex alloys containing, e.g. more than 5% Mo, but has not previously been suspected as a constituent of 18/8/Mo/Ti. As with steel F1, TiC was absent but TiN appeared.

TABLE VIII

Phase	<i>Alpha</i>	<i>Gamma</i>	<i>Sigma</i>	<i>Chi</i>	<i>Tau</i>	TiC	TiN	Cr ₂₃ C ₆
Times present	4	5	1	1	4	2	3	1
Procedure 1	4	3	1	0	2	2	0	1
Procedure 2	1	2	1	1	3	2	2	0
Procedure 3	2	1	1	1	4	2	2	1
Procedure 4	4	3	0	0	0	1	2	0
Procedure 5	3	3	0	0	0	2	2	0
Procedure 6	2	4	0	0	1	2	3	0

General Conclusions

On the basis of the above results, procedure 3—alcoholic 10% hydrochloric acid, 0.08 amp./sq. cm., 40° C. max—gives the best results for phases other than *alpha* and *gamma*. It is clear that the technique is valuable, for it has provided definite evidence of the presence of chromium carbide not obtainable by other means, the formation of *chi* in reheated 18/8/Mo/Ti, and indications of changes in the composition of "TiC."

PART II—STRUCTURAL CHANGES IN 18/8/TI AND 18/8/Nb STEELS CAUSED BY HEATING

It is now widely recognised that stabilised 18/8-type steels, although showing very good resistance to disintegration in the Hatfield or Strauss test after heating at 650° C., may show a reduction in their resistance to nitric acid as a result of heating.

The various points involved may be summarised as follows:—

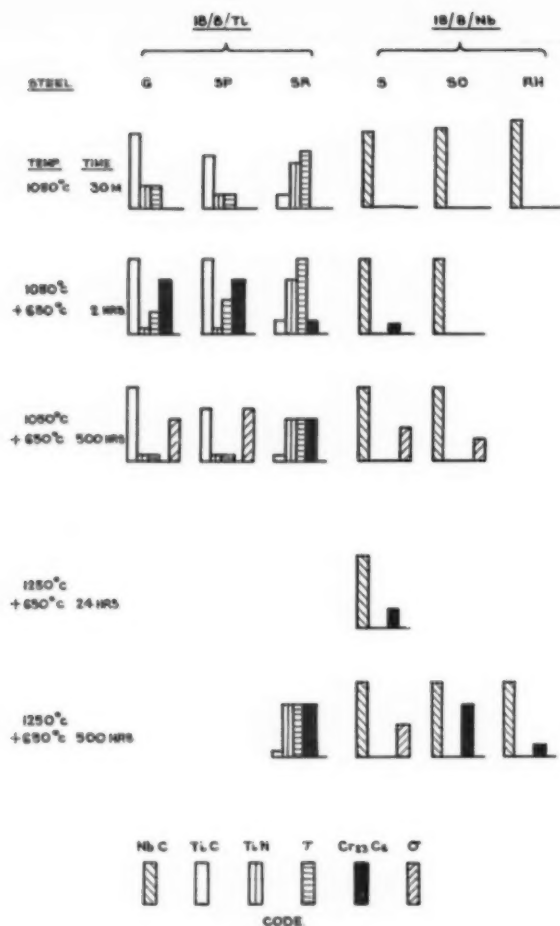


Fig. 4.—Phases (other than alpha and gamma) found on a limited number of samples of three 18/8/Ti and three 18/8/Nb steels.

- (1) Many 18/8/Ti steels softened at 1,050° C. and reheated at 600°–750° C. show a loss of corrosion resistance.
- (2) If the softening temperature is higher, the effect of reheating is magnified.
- (3) Reheating at 880°–900° C. has no detrimental effect on the corrosion resistance of softened material, and improves that of material heated at 650°–750° C.
- (4) If material heated at 880°–900° C. is further heated at lower temperatures, no reduction in resistance is found.
- (5) If the steels are heated to very high temperatures (above 1,200° C.), their corrosion resistance is lowered independent of reheating. Nicking attack close to welds is probably a result of this.
- (6) 18/8/Ti steels are more susceptible to these effects than 18/8/Nb steels, though the latter are not immune.
- (7) Reduction of carbon content and increase of Ti/C ratio reduce the severity of the effects in 18/8/Ti steels.¹⁰

Points 1–4 above have been related on the theory that some carbon remains in solution at the softening temperature and may precipitate as chromium carbide on reheating. Further heating at 880° C. leads to replacement of this chromium carbide by titanium carbide. So long as chromium carbide is present, the corrosion resistance of the steel is low.

It is not clear whether point 5 demands a separate explanation, or whether corrosion of specimens quenched from, e.g. 1,350° C. and not reheated may be adequately explained on the basis of precipitation of chromium carbide during the quenching process.

Present Work

The work described below covers the examination of three 18/8/Ti steels and three 18/8/Nb steels after softening and reheating, the primary objective being to find whether the chromium carbide found could be correlated with the corrosion resistance. The composition of the steels used is shown in Table IX. The specimens were softened by heating at 1,050° C. or 1,250° C., and then reheated for periods varying between 5 min. and 500 hr. at temperatures ranging from 500°–900° C. Most attention was paid to specimens softened at 1,050° C.

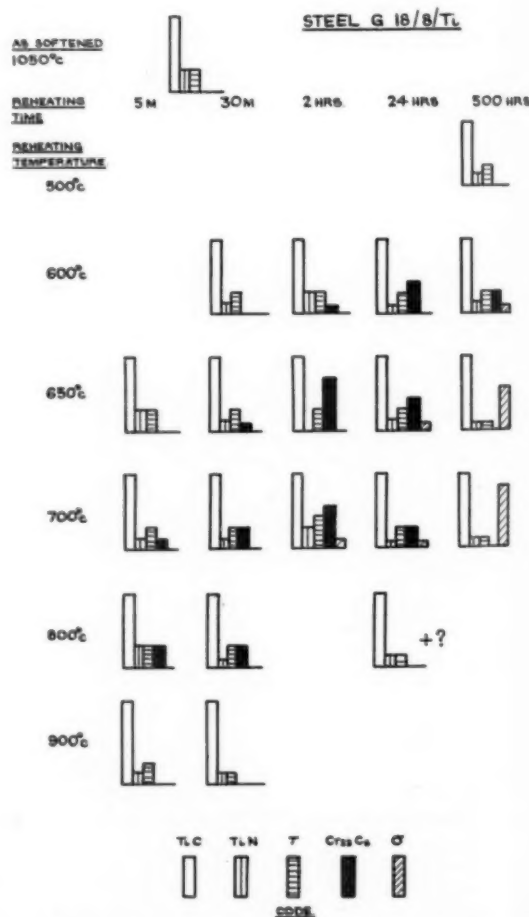


Fig. 5.—Phases (other than alpha and gamma) found in 18/8/Ti steel G.

TABLE IX.—ANALYSES OF 18/8/Ti AND 18/8/Nb STEELS

Type of Steel	Code	Composition (%)								
		C	Cr	Ni	Si	Mn	Ti	Nb	N	
18/8/Ti	G	0.12	18.4	8.0	0.63	0.47	0.12	0.72	—	0.01
	SP	0.10	18.7	7.8	0.90	0.46	0.17	0.66	—	0.01
	SR	0.06	17.9	7.9	0.65	0.57	0.10	0.32	—	0.02
18/8/Nb	S	0.16	17.8	8.1	0.82	0.47	0.15	—	1.50	0.03
	SO	0.11	18.8	11.2	0.51	1.2	0.17	—	1.3	0.05
	RH	0.10	18.7	10.1	0.59	0.81	0.22	—	1.24	0.05

After heat treatment, specimens were descaled by pickling and then subjected to selective solution in 10% alcoholic hydrochloric acid at 0.08 amp./sq. cm. using the apparatus shown in Fig. 3. The extracts were then examined using the same techniques as in Part I. Microexamination of the specimens, and in some cases corrosion tests, were also carried out.

Results

Figs. 4-7 show the phases other than *alpha* and *gamma* found in the steels, Fig. 4 showing results on a limited number of samples from all six steels, and Figs. 5-7 the fuller results on steels G and SP (18/8/Ti), and S (18/8/Nb). Blank spaces indicate that no tests were done. The relative abundance of the phases in the

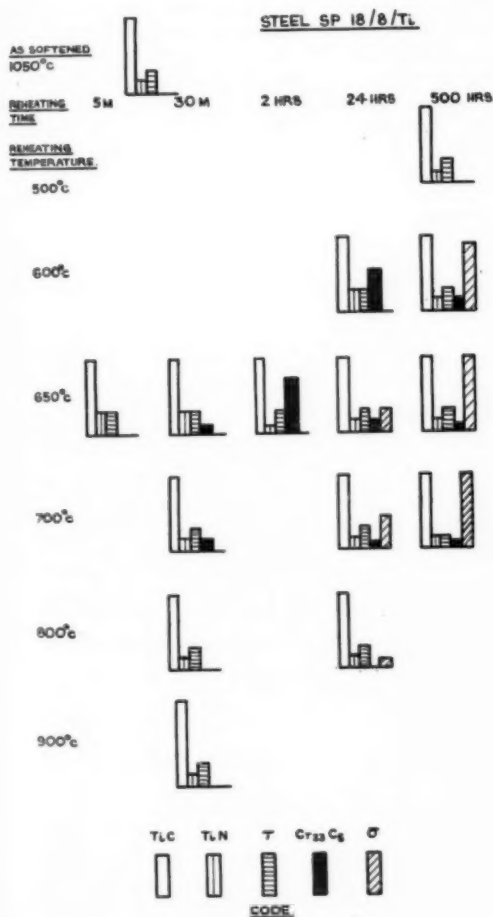


Fig. 6.—Phases (other than *alpha* and *gamma*) found in 18/8/Ti steel SP.

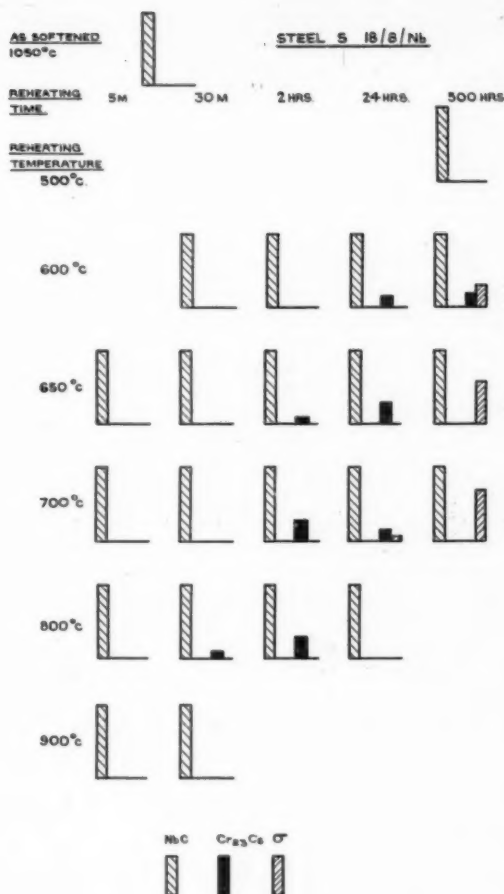


Fig. 7.—Phases (other than *alpha* and *gamma*) found in 18/8/Nb steel S.

extract is indicated by the height of the column, using arbitrary scale divisions related to the terms "s, m, w, vw, vvw" (strong-very very weak) used in describing the X-ray films. It will be seen that TiN has been recovered from all three 18/8/Ti steels, even though in the initial tests on the use of alcoholic hydrochloric acid described in Part I, this phase was not always recovered. The improvement possibly arises from the better control of the extraction procedure achieved with the improved apparatus.

It will be seen that, in each of steels G, SP and S, there is clear evidence of the formation of chromium carbide after a limited period at temperatures in the range 600°-700° C., while further heating at the same temperature causes the appearance of *sigma* and disappearance of the chromium carbide. In steel SR, chromium carbide was found but did not change to *sigma*; in steels RH and SO, the limited number of specimens examined did not establish the sequence, though *sigma* appears in both after certain heat treatments. Steel SR is notable in that TiN is much more prominent than TiC, and the strongest phase is that termed *tau*. This phase is present in all the 18/8/Ti steels; it is not clear that the quantity present is affected by the state of heat treatment. The phase *tau*

TABLE X

Steel	Code	Corrosion Rates (mm./yr.) in 70% Nitric Acid at 70° C.	
		AC 1,050° C.	1,050° C. + 2 hr. 650° C.
18/8/Ti ..	G	0.028	0.28
	SP	0.034	0.072
	SR	0.020	0.12
18/8/Nb ..	S	0.015	0.058
	SO	0.010	0.031
	RH	0.015	0.072

does not appear in the 18/8/Nb steels, nor is there any indication of a comparable phase.

Examination of Figs. 5-7 shows that the effects of time and temperature on the formation of carbide and its conversion to *sigma* follow a logical course. With steel G, no chromium carbide appears even after 500 hr. at 500° C., but as the temperature is raised to 800° C., it appears more and more quickly. At 900° C. it does not appear. *Sigma* is not found at less than 500 hr., but the quantity found after this period increases with the temperature in the range 600°-700° C. At 800° C. no *sigma* appears, and the chromium carbide evident after ½ hr. has dispersed after 24 hr. No 500 hr.-800° C. specimen was prepared, as it was assumed that at this temperature reactions would be fairly rapid. At 900° C. it appears that chromium carbide can exist only for a period less than 5 min. if at all.

With steel S, results are very similar. Chromium carbide appears more slowly than in steel G, but follows the same rules; in particular, after 24 hr. at 800° C., it has disappeared even though no *sigma* has formed. *Sigma* again does not appear stable at 800° C.

Correlation with Corrosion Resistance

Corrosion tests in 70% nitric acid at 70° C. have been carried out on each steel in the "A.C. 1,050° C." and the "1,050° C. + 2 hr. 650° C." conditions. The results, which are shown in Table X, may be examined to see to what extent the attribution of the increased conversion, after heating at 650° C., to chromium carbide formation may be justified.

Apart from SP, the 18/8/Ti steels show a definite inferiority to the 18/8/Nb steels as regards this effect. Comparison with the quantity of chromium carbide present, as very roughly indicated in Fig. 4, shows a considerable discrepancy. Steel SP forms as much carbide as G, SR forms rather little. The corrosion results are the reverse of what would be expected, SR being considerably affected and SP not greatly so. Again, carbide is found only in 18/8/Nb S, whereas the corrosion results suggest that it should be present in RH to a greater extent.

In any case, it is clear that chromium carbide can appear in some 18/8/Nb steels. The generally acknowledged superiority of these steels can therefore only be related to chromium carbide if considerations of quantity are taken into account, and on the admittedly few results available it does not look as if the relationship is simple.

Carbide versus Sigma

A few corrosion tests (in 70% nitric acid at 70° C.) have been carried out to study the relation between corrosion rate and the change from carbide to *sigma*, and the results are shown in Table XI. Figures given for the 1,050° C. and 1,050° C. + 2 hr. 650° C. conditions differ from those in Table X, because the details of the testing technique were not the same.

It appears from these figures that the liability to high corrosion rates only exists when chromium carbide is present. When heating is carried out for such a period that *sigma* replaces the carbide, the corrosion resistance recovers. It is generally agreed that the effect of precipitated chromium carbide—e.g. in plain 18/8 steels—is due not to the presence of the carbide but the depletion of the chromium content of the matrix around the carbide particles. The mechanism of the recovery of resistance requires careful consideration.

Sigma contains more chromium than the basis metal. Carbide contains an even higher percentage of chromium, but the total amount of carbide which can form is strictly limited. The amount of *sigma* which can form is limited by other factors, but there is no doubt that more *sigma* might form than carbide. Hence there is no prime reason for supposing the change carbide to *sigma* releases chromium; it is very likely to do the reverse. The improvement in corrosion resistance is, therefore, not due to the carbide → *sigma* change.

There can be little doubt that the improvement is due to diffusion of chromium from the bulk of the austenite to replenish the depleted zones adjacent to the carbide particles. The sequence of events is uncertain; i.e. whether replenishment leads or follows the appearance of *sigma*. Since *sigma* formation probably involves withdrawal of extra quantities of chromium from the matrix, it is likely that *sigma* only forms after considerable levelling-out of the chromium content has taken place. This implies that the improvement in corrosion resistance could take place while carbide was still present, and before *sigma* formed: the figures in Table X give no information on this point.

Tau-Phase

The electrolytic extracts from steel SR consisted principally of TiN and *tau*, and this steel was examined further to get more information as to the nature of the *tau*-phase. It was found that simple solution of the steel in hot concentrated hydrochloric acid gave a similar residue to that produced electrolytically, and by the simpler technique considerable quantity of the residue was produced.

By X-ray emission spectrography, it was apparent that a large amount of silicon was present, but it was suspected that some or all of this might be present as amorphous silica. Tests showed that flotation in bromoform and treatment in cold concentrated sodium hydroxide reduced the silicon content to the point at which it could not be detected by X-ray spectrographic analysis, but the treated residue was still composed of TiN and *tau*, with some TiC.

Chemical analysis of the treated residue showed:—

Ti	..	..	..	..	..	..	69.0
N	..	..	..	..	..	..	9.7
C	..	..	..	..	..	..	5.7
S	..	..	..	..	..	..	4.4
							88.8
Loss on gentle drying							10.0

If the carbon and nitrogen are assumed to be present as TiC and TiN, calculation shows that the residual titanium and sulphur contents correspond almost precisely to Ti₂S. Several sulphides of titanium are described in the literature, but none corresponds to the *tau*-phase. However, there is a very strong presumption that the *tau*-phase is a titanium sulphide.

TABLE XI

Steel	Heat Treatment	Phases Present (chromium carbide and σ only)	Corrosion Rate (mm./yr.)
G (18/8/Ti)	A.C. 1,050° C. 1,050° C. + 2 hr. 650° C. 1,050° C. + 300 hr. 650° C. 1,050° C. + 300 hr. 750° C.	— Carbide σ σ	0-032 0-19 0-023 0-02
S (18/8/Nb)	A.C. 1,050° C. 1,050° C. + 2 hr. 650° C. 1,050° C. + 24 hr. 650° C. 1,050° C. + 300 hr. 650° C.	— Carbide Carbide σ	0-023 0-05 0-10 0-05

Other work in hand concerns a steel of composition approximately 20/30/1—Cr/Ni/Ti and it has been found that the τ -phase occurs in residues from this steel. More recently it has been reported¹¹ in 8% Cr/Mo/Ti steels. The authors of this paper termed it the "Y-phase," but correspondence has left no doubt that it is the same phase. It is considered desirable to avoid the letter Y in view of possible confusion with the Greek γ when hand written, and there now being some fairly definite evidence as to its nature, it is not unreasonable to consider that it qualifies for a Greek letter.

General Conclusions

(1) The method of concentrating minor phases by anodic attack is valuable and greatly assists recognition of phases present in small quantities. Of the six techniques tried, use of 10% hydrochloric acid in alcohol appears most satisfactory for austenitic steels. A cell has been designed in which extraction conditions can be controlled more closely than with simpler cells.

(2) The presence of chromium carbide in 18/8/Ti and 18/8/Nb steels after reheating at 600°–700° C. has been demonstrated. The appearance of this phase in 18/8/Nb steels invalidates the simple theory put forward to explain the superiority of 18/8/Nb steels as regards the effect of heating at 650°–750° C. Chromium carbide may, however, still be at the root of the matter.

(3) Other workers have postulated that σ forms on carbide nuclei. This has been clearly demonstrated with the steels examined.

(4) The χ -phase has been found in an austenitic steel containing only 3.2% Mo.

(5) A phase termed τ has been found and shown probably to be Ti_2S .

APPENDIX I

Characteristic Interplanar Spacings (Powder Data)

Tabulated below are the lattice spacings which give lines on powder photographs by which TiN, τ , σ , and chromium carbide are identified. Similar data for α , γ , TiC and NbC may be found in ref. 12 and for χ in ref. 13.

(1) TiN Å	(2) τ Å	(3) σ Å
2.45 ms	2.77 mw	1.212 mw
2.12 s	2.69 vw	1.132 w
1.497 ms	2.22 vs	1.110 vw
1.276 m	1.963 vw	1.052 vvw
1.223 w	1.859 w	1.045 vw
1.059 w	1.736 vvw	1.008 ms
0.971 mw	1.596 ms	0.953 vw
0.947 ms	1.542 mw	0.924 mw
	1.381 m	0.916 vw
	1.298 mw	0.912 w

(3) σ Å

2.367 vw	1.241 ms+
2.281 m	1.229 w
2.125 s	1.221 vw
2.070 ms	1.207 ms—
2.024 ms—	1.200 w?
1.972 ms+	1.187 vvw
1.928 s+	1.177 vvw
1.883 ms	1.167 mw
1.840 w	1.144 mw+
1.801 vvw	1.067 m+
1.763 w+	1.038 m+
1.392 vw	1.009 ms
1.375 vw	1.002 m
1.329 mw	0.992 m
1.314 vvw	0.985 ms
1.257 ms	0.964 mw

(4) (Fe, Cr)₂₃C₆ Å

3.20 vw	1.248 s
2.65 vw	1.223 ms
2.37 m—	1.184 m
2.16 m	1.163 m+
2.035 vs	1.155 vvw
1.871 m—	1.110 vw
1.789 m	1.082 s
1.764 mw	1.064 ms
1.674 vw	1.019 vvw
1.614 vw	0.985 w
1.595 w	0.968 mw
1.484 vvw	0.956 mw
1.468 vvw	0.938 vvw
1.333 vvw	0.927 s
1.324 mw	0.900 w
1.284 mw	

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T.I.-Reynolds Metals Agreement

SUBJECT to Treasury approval and to completion of formalities, Tube Investments, Ltd., has concluded an agreement with the Reynolds Metals Group, of the U.S.A., to combine the interests and activities of both groups in the aluminium industry in the U.K. The agreement provides for the formation of a new company to be called Reynolds Metals and T.I. Aluminium, Ltd., which will take over the existing aluminium undertakings of T.I. Aluminium, Ltd. The company will be owned 50:50 by T.I. and Reynolds.

The combined resources of both groups—technical, research, commercial and metal supplies—will support the new company, for which an active development and expansion plan is intended. The chairmanship of the company will alternate between Sir Ivan A. R. Stedeford, K.B.E., chairman of Tube Investments, Ltd., and Mr. R. S. Reynolds, Jnr., president of the Reynolds Metals Company. Sir Ivan Stedeford will be the first chairman.

New H.Q. for Honeywell-Brown

ALMOST half a million cubic feet of modern architecture will accommodate the administration of all divisions—industrial instrumentation, thermostatic controls, and micro switches—when the new head offices of Honeywell-Brown, Ltd., are opened in June 1958. A new training school will be housed in one part of the building, where, in a fully equipped lecture theatre and laboratory, employees and users from all over Europe will be taught how to apply modern instrumentation to industrial processes and heating and air conditioning systems. The school will also provide courses on micro switching. Multi-purpose telephone receivers will combine outside call and internal facilities in one instrument. An outside caller will be able to hold a conference with up to four inside speakers, speaking from their own desks. This dual purpose facility, the first of its kind in this country, has been made possible by arrangement with the G.P.O.

The Production Engineering Research Association

By D. D. Morgan

Information Manager

Production techniques have an important part to play in the improvement in quality and reduction in cost of the products of the engineering industry. Besides providing a brief description of the investigations in progress in the laboratories of the Production Engineering Research Association, the author refers to the methods adopted for ensuring prompt application of the results of this work.

IMPORTANT developments which have taken place during the past year include the occupation of a new research block and the establishment of a new Education and Training Department. Existing services have been expanded to meet the growing demands of members for assistance in overcoming a wide variety of production problems, and new services have been introduced to provide members with the maximum assistance in securing the prompt and effective application of improvements in production techniques pioneered by PERA.

Twelfth Annual General Meeting

At the Twelfth Annual General Meeting of the Association, recently held at Melton Mowbray, Sir William Stanier, F.R.S., was re-elected President of the Association. The following were newly elected to PERA Council: Mr. F. V. Everard (Works Executive Director, Belliss & Morcom, Ltd.); Mr. E. A. Hyde (Managing Director, Wickman, Ltd.); Mr. J. Russell Lang (Director, G. & J. Weir, Ltd.); Mr. F. P. Laurens (Managing Director, Powers-Samas Accounting Machines, Ltd.);

and Mr. M. I. Prichard (Deputy Managing Director, F. Perkins, Ltd.). Mr. Prichard had previously been co-opted. The following retiring members of Council were re-elected: Mr. W. Armstrong (Director, Armstrong (Leeds), Ltd.); Mr. L. L. Bott (Works Director, Davey, Paxman & Co., Ltd.); Mr. J. O. Bowley (Director and General Manager, A.E.C., Ltd.); Mr. B. H. Dyson (General Manager, Overseas Production, Hoover, Ltd.); Mr. J. S. Gabriel (Chairman, Charles Churchill & Co., Ltd.); Mr. J. W. Garton (Chairman and Managing Director, The Hoffmann Manufacturing Co., Ltd.); Mr. E. W. Hancock (Director and General Manager, Humber, Ltd.); Dr. H. Schofield (Chairman, J. A. Crabtree & Co., Ltd.); and Mr. A. L. Stuchbery (Chief Technical Engineer, The Metal Box Co., Ltd.).

The Chairman's Report stated that, during 1956, work was carried out on 32 general investigations, covering press-working, machine tools, lubricants, thread rolling, cutting tools, deburring, vibration, machinability of materials, work positioning and handling, surface finish, etc. Reports were issued on a number of researches, including investigations of tap accuracy and perfor-



An exterior view of PERA's new research block.



Part of the interior of the new research block.



This 1,000 ton press has greatly extended the scope of research on impact extrusion

mance, drill performance and geometry, the determination of blank diameters for rolling unified screw threads, impact extrusion of steel, the effect of reamer shape and cutting conditions on the accuracy and surface finish of reamed holes in steel, the suitability for workshop use of the plastic replica method of surface finish measurement, and methods of deburring machined components.

During the year, 155 practical investigations were also carried out for individual members into tool grinding and inspection, finish blanking, chip breaking, vibration in machine tools and other production plant, corrosion, tapping, metallurgical aspects of cutting tools and punches, drilling etc.

Finance

Income for the year totalled £203,934, an increase of £44,645 over 1955. In 1956 the Association earned the maximum D.S.I.R. grant of £75,000. The response by members to the modified subscription scale was very satisfactory, and the increased income will enable the Association to extend the facilities and services for the benefit of members.

The total membership at the end of 1956 was approximately 500 firms. Industrial subscriptions increased from £79,000 in 1955 to £120,000 at the end of 1956, an increase of over 50%. Although the economic situation and trading conditions have affected the engineering industry during the past year, interest in PERA and its activities has continued to increase, resulting in a steady growth in membership.

Education and Training

Following the success of last year's experiment of providing intensive training courses for key personnel at all levels in industry, a new Education and Training Department has been established. The former research laboratories have been converted into a training centre with lecture theatres, study rooms, demonstration bay, etc. Greatly improved lecturing facilities and accommodation are therefore available for all courses. Practical demonstrations of production techniques have also been facilitated, as equipment has been specially allocated for this purpose.

Over 500 key personnel in industry attended the experimental series of five-day courses on improved production techniques held at PERA from April to October, 1956. At the request of members, the general course on improved production techniques has been repeated this year, and specialized courses on a variety of subjects have also been arranged. The subjects covered by the course on improved production techniques include metal forming, automation, metal cutting, machine tool utilisation, method study, and inspection. A new series of courses on metal cutting began during June and are being attended by foremen, shop managers, planning and process engineers, superintendents, tool engineers, methods engineers, etc. Case studies and group discussions have been found to play a very important role in stimulating member firms' personnel to seek opportunities for applying the Association's recommendations in production operations. In addition to the examination of the effects of changes in well established production techniques, the courses include an outline of the advantages of recently developed production techniques, together with sufficient information on the economics of these techniques to assist members in deciding which are the most suitable for application in their factories.

Short refresher courses are also being held for workshop personnel such as foremen, tool grinders, etc., on machine tool maintenance, press setting, tool and cutter grinding, etc.

Nearly twenty young engineers are at present attending the Association's six-month course. The purpose of the course is to inculcate a progressive and enlightened outlook on all aspects of production, including even the most familiar established practices. Each course includes practical experience with PERA research teams, lectures on various aspects of production from



Part of the demonstration bay in the new Education and Training Department

senior research engineers, a series of organised discussions, and visits to factories specially selected to demonstrate the application of up-to-date production techniques in various industries. The course has now been taken by about 100 young engineers from member firms. Companies who have participated in the scheme include manufacturers of light and heavy electrical equipment, motor cars, locomotives, diesel engines, machine tools, boilers, small tools, metal boxes and other pressings, aircraft, etc. Each student is individually trained by PERA engineers, and participates directly in the solution of a variety of production problems.

Research

Metal Forming Investigations

Investigations have been continued to determine the relative efficiency of a number of lubricants when deep drawing various materials. The results of this investigation will provide industry with reliable evidence on the effects of a wide range of lubricants which are at present selected largely by trial and error. Continuation of work in another deep drawing investigation has confirmed that substantial increases in depth of draw can be achieved under conditions which differ markedly from conventional practice.

Thread Rolling

Industrial opinions on the method of calculating blank diameters vary considerably, and in order to eliminate the costly trial and error which this entails, the Association carried out an investigation to determine sizes of blanks for rolling Unified Fine and Coarse screw threads. The recommended blank sizes given in the report issued to members include an allowance for possible thread form errors. This report is proving of great assistance to draughtsmen, designers, and production engineers.

Finish Blanking

Research has been continued into the PERA finish blanking technique which produces pressings with smooth edges, in contrast to the relatively rough edges produced by conventional blanking techniques. This technique frequently eliminates expensive shaving or

machining operations in the production of pressings, and is being applied in a growing number of industries in the manufacture of cars, electrical goods, etc. In one firm a steel component finish blanked in one operation compared favourably in quality with components previously requiring 11 operations, and in another firm a saving of £3,000 was effected in the production of the first component to which finish blanking was applied. Still wider application of the technique is expected when research results into the finish blanking of high tensile steels are made available to members. The most suitable conditions are also now being established for the finish blanking of a variety of other materials in a range of thicknesses.

Cold Extrusion

Considerable progress has been made in investigations into the impact (cold) extrusion of steel. The industrial and commercial implications of this development are very great, as cold extrusion produces relatively complex parts quickly and accurately. Experiments have recently been started on the cold extrusion of large steel components using a 1,000 ton press, which is believed to be the only one of its kind in Europe, and which greatly extends the range of the Association's investigations into this highly efficient production process. Research is at present being carried out into the properties of steels for impact extrusion, the variations in extrusion pressure with percentage reduction in area, and the conditions of lubrication required for backward extrusion. Despite the tremendous possibilities of the cold extrusion process for reducing capital expenditure, floor space, handling, operation times, and material consumption in the production of a wide range of products, application of the technique in Britain has been restricted by the lack of reliable data on tool design and on the extrusion properties of materials. Materials such as steel have been industrially extruded for about 20 years in Germany and approximately 10 years in the U.S.A. whereas very few British firms have yet taken advantage of the process. However, development work which the Association is at present carrying out for various firms is expected to result in savings of the order of £60,000 per year in the production of one type of component alone.



Studying the operating characteristics of a mechanical hand.

Metal Cutting Investigations

Following the very successful series of researches into the drilling of cast iron, investigations have been carried out to determine the most suitable point shapes for drilling various steels. Significant increases in drill life have been achieved with point shapes differing markedly from those conventionally used in production workshops. Current research includes an investigation on an automatic lathe to compare three types of high speed steel when machining alloy steel. The opportunity is also being taken during this investigation to investigate the relationship between tool wear and workpiece diameter. Research has recently been initiated to compare the performance of various cutting fluids and the effects of different methods of applying cutting fluids when machining high tensile nickel-chrome steel with carbide tools.

An investigation into the effect of reaming conditions on hole accuracy and surface finish showed that there are critical values of cutting speed and feed rate, above which the accuracy and surface finish of reamed holes deteriorate rapidly. As these critical values are the limiting factors preventing the use of higher cutting speeds and feed rates in cutting operations, it was considered important to determine whether improvements in performance could be achieved by changes in reamer shape. Tests have therefore been carried out to determine the effects of reamer shape on the accuracy and surface finish of holes reamed in low carbon steel. Changes in rake and circular land width influenced hole surface finish, and the test results also indicated that swarf jamming has an important influence on reamer performance. Other factors investigated included chamfer angle and flute length, and the effect of built-up edge on accuracy and surface finish. The formation of a built-up edge and factors affecting chip-tool interface friction and temperature were also considered. Further progress has been made in the Association's survey of high speed hobbing, and an assessment is being made of the effect on hob life of such factors as the number of hob starts, helix angle, and the number of teeth in the gear. Studies are also being made of hob wear and of the effects of slight variations in hob tooth formation on hob life.

Tool Grinding

Field investigations into problems concerned with cutting tool performance have emphasized the need for improved grinding techniques and a greater degree of control. An investigation in which conventional and unorthodox methods of grinding carbide tools were studied indicated that the speed and ease of grinding associated with a particular method were of considerable economic significance. The effect of the method of grinding on carbide tool performance was also investigated.

Recommendations based on the researches are being applied in industry, and savings in the form of reduced grinding wheel costs and longer tool life between regrinds have been reported.

Machine Tools

An investigation into the accuracy and performance of several makes of cylindrical grinding machine has been completed, and the final report is about to be issued. Substantial progress has also been made in an



Dr. D. F. Galloway (right) discussing metal cutting research with participants in an intensive five-day course.

investigation into various aspects of machine tool slideway lubrication and slideways. The first part of the investigation has been completed, and a draft report is being prepared on the influence of scraped surfaces, lubricant viscosity, load per unit area, and sliding speed on the transition from boundary to hydrodynamic lubrication. Practical tests are also being carried out to determine the friction properties of various lubricants and machine tool slideway materials.

Machine tool vibration is a complex phenomenon which can only be investigated with the aid of specialized research equipment and highly trained scientific staff. Thus, although vibration often restricts output and impairs product quality in industry generally, great difficulty has been experienced in finding solutions to vibration problems. In recent years, however, the Association has made some significant advances in this field, and it is becoming essential for industry to have the trained technologists who can interpret and apply the results of the Association's researches. For this reason a number of firms in the machine tool industry have seconded senior staff to the Association for periods of up to 12 months or more. These engineers are assisting PERA staff engaged on practical investigations, and are also receiving advanced academic training in subjects necessary for complete understanding of vibration phenomena.

One of the most important current vibration investigations is concerned with the development of stability devices to eliminate self-excited chatter when using large overhanging boring bars. Progress has also been made in identifying modes of vibration occurring in cylindrical grinding machines, and also in exploring the lobing characteristics of cylindrically ground workpieces caused by forced vibrations. Methods have also been developed for determining the natural modes of vibration of centre lathes. Preparatory work for further research into machine tool structures and stability devices has been started.

Member firms are now making much greater use of the facilities provided by the PERA vibration team, especially during the development of new equipment and when assistance is required in overcoming vibration problems encountered in production.

Automation

The first part of an operational research into automation has been completed with the preparation of a report on work positioning and handling equipment used in conjunction with conventional and special machine tools and processes to reduce or eliminate manual operations. Visits are being made to selected firms to obtain practical data and information concerning applications of various types of automation equipment. The reports to be issued will deal with hoppers and selector devices, work loading and unloading equipment, work clamping equipment, conveying equipment, applications of work-handling equipment in machining and pressworking operations, and transfer machines. Member firms have seconded staff to the Association in order to expedite these investigations.

Deburring

The operational research into deburring has been completed with the publication of a report on the prevention and removal of burrs on sheet metal pressings. Examples of deburring practice and press tool design contained in the report are based on visits to the works of a number of companies and on a summary of published information. Methods of burr removal considered included chemical treatments such as electrolytic polishing and etching, abrasive blasting, rotary files and brushes, abrasive tools and belts, chamfering and deburring tools, and special purpose deburring machines.

Information Services

Very heavy demands are still being made on all information services. For example, in the past twelve months more than 2,000 requests for technical assistance have been received from members on every major aspect of production, including factory layout, selection of plant and equipment, plastic moulding, machining, press working, maintenance, inspection, automation, tool design, metal forming, design for production, etc. Substantial economies have been reported following application of the Association's recommendations in industry, including an increase of more than 30% in the output of a works manufacturing mechanical handling equipment. In another firm, the output of metal furniture will be increased by approximately four times in rather less than twice the original floor space with relatively small capital expenditure. The Association has also assisted a member firm to double its output in the same floor space by completely revising tooling, methods, layout, etc.

Further extensions have been made to the library to accommodate the continually increasing collection of books, periodicals, trade literature, research reports, etc. The extensive collection of trade literature is a particularly valuable feature of the library, and over 25,000 separate catalogues and pamphlets covering machine tools, materials handling equipment, foundry plant, office equipment, instruments, small tools, etc. have been collected from many countries. To facilitate searches for information, a comprehensive classification scheme has been developed which takes into account the special needs of production engineers. In the past twelve months, over 250 requests for specific information about many different aspects of production were answered by the library staff, and over 8,000 requests were received for the loan of literature.

About 750 liaison visits were made to firms to assist in overcoming specific production problems, and to stimulate the most effective application of research results and all information and educational services. The Mobile Unit visited approximately 150 firms in Scotland and the North of England.

Films have been made by the PERA film unit on a variety of subjects, including cutting fluids, drilling, and carbide tools. These films give practical guidance to industrial personnel in applying the improved production techniques pioneered by PERA, and are playing an important part in stimulating the prompt and effective use of the results of the Association's researches into metal cutting, metal forming, machine tools, etc. A film is at present being made on methods improvement, in collaboration with a number of member firms.

Re-organisation of British MonoRail

CONTROL of British MonoRail, Ltd., has been acquired by a group of industrialists and financiers, headed by Mr. J. Dallas, who have purchased the entire British shareholding—approximately 80% of the issued capital. The company has now been reorganised to cope with rapid expansion.

Originally formed in 1952, the company will continue to operate from Wren Works, Chadderton, Lancs., as manufacturers of high quality automatic transfer and overhead handling equipment. They will also develop still further their consultancy activities, which include the planning, supply and erection of complete mechanical handling installations. When the company was first formed, 20% of the shares were given to the American MonoRail Company in return for full co-operation, including drawings, patents, goodwill and staff training facilities. This arrangement will continue under the new control, so that the British company will be able to utilise the "know how" of one of the leading mechanical handling organisations in the world.

Mr. J. Dallas has been appointed chairman and managing director of British MonoRail, Ltd. He was for 12 years senior consultant with Production Engineering, Ltd., and formerly with Wm. Denny & Bros., Ltd., and Ferranti, Ltd. Mr. J. Lund, the new technical director, is well-known in the machine tool industry. He was chief engineer for 14 years with the Newall Engineering Group, and at one time was with John Lund, Ltd.—a family-controlled firm—where he was primarily responsible for the design of Precimax grinders.

Nuclear Reactor Starting Equipment

THE first commercial production in this country of neutron source tubes (which will start up the two reactors at the Bradwell nuclear power station) is being undertaken by the Tube Investments subsidiary, Talbot Stead Tube Co., Ltd., on behalf of the Nuclear Power Plant Co., Ltd. Neutron source tubes consist of an antimony rod surrounded by a beryllium tube and enclosed in an outer sheath of stainless steel. The tubes are activated by insertion in a working reactor, as a result of which the emission of gamma rays from the antimony is initiated. These rays in turn cause neutrons to be released from the beryllium metal. This neutron source is used to initiate the chain reaction in a reactor under controlled conditions.

History of the Railway Axle

From Faggotted Wrought Iron to Forged Steel

THE first modern industrial axles were undoubtedly of iron, and were designed primarily for road vehicles and light shafting. The forerunner of the modern railway axle was undoubtedly the "Patent Iron Axle" invented by James Hardy, a Baptist Minister, in 1834. This invention originated in a contemplation by the inventor of the sections of an orange, and was first marketed and made on a considerable scale by the Patent Shaft and Axletree Company of Wednesbury.

With the extension of railways in 1841, the demand for axles enormously increased, and Hardy's axle was adapted for use under railway carriages, wagons and locomotive tenders. Before 1834 axles for coaches (and a limited number used for railway vehicles) were constructed without any special endeavour to achieve the desired strength. They were manufactured by welding together layers of flat or square bars under the forging hammer. Flat tools were used, which produced a round shaft having a surface of irregular texture and uncertain transverse strength. As a result fracture was all too common.

Hardy's axle was known as the "faggotted" or "radial" axle, and was made in the following manner. A forged or rolled round iron bar made from material $2\frac{3}{4}$ to 3 in. diameter formed the centre of the faggot. Around this bar were placed special sections known as radials, which were rolled so as to fit round any diameter. When built up, the faggot measured from $7\frac{1}{2}$ to 9 in. diameter by 5 ft. 6 in. in length. This was forged down at a welding temperature in a hammer-tool with only one large hole. When its diameter had been reduced to about 6 in., it was cut to the requisite length.

Blooms so produced were afterwards formed into finished axles of the required diameter in properly formed tools. This was a separate operation. It should be noted that an original specimen of this early axle is still in the possession of the Patent Shaft and Axletree Co., and was exhibited by them at the Wembley British Empire Exhibition in 1924. This method of forging axles was so much better than the original method that it was widely adopted.

Krupp's claim to have been the first in the world to manufacture ingot steel axles, supplied by them in 1848 to the Berlin-Minden Railway, and these were made of crucible cast steel. This claim may be true, but it is fairly clear that the steel axle did not come into widespread use until 1860-1865, when its manufacture by the Bessemer process made steel an economic possibility for axles. The transition from iron to steel was, of course, gradual. Bessemer did not take out his patent until 1856, and he offered it to Lloyd, Fosters & Co. of Wednesbury, the predecessors of the Patent Shaft and Axletree Co., absorbed by the latter firm in 1867 under the name of the Monway Works. Lloyd, Fosters made railway wheels many years before the Patent Shaft and Axletree Co., but they mounted these on the Hardy axles.

The axle and tyre departments of the Monway works

were completed in 1854, a plate mill being added at a later date. This firm first tried steel for axles in 1860, and it was, therefore, some time after this date that the general adoption of steel began. Messrs. Robert Heath and Low Moor were making steel axles in 1865. The earliest reference to axles manufactured from Bessemer steel concerns those made by Charles Cammell & Co. of Sheffield, which were tested in June, 1866.

Iron axles continued to be manufactured in small quantities until 1890, these being ordered mostly, if not wholly, by the Japanese Railways, but Taylor Bros. supplied axles of best Yorkshire iron to the London, Brighton and South Coast Railway as late as 1900, and locomotive axles to an American railway until 1922.

Some interesting figures are available concerning the output of steel axles. In 1880, 14 wagon axles were produced per shift, and this rose to 18 and 20 by 1895. Towards the end of the year 1900 it had risen to 22 per shift, and at this figure, in most works, it remained for several years, but by 1905 four Sheffield firms at least had attained outputs of 26, 24, 22 and 24 axles per shift respectively. These outputs were all obtained by the old method of forging an axle at two heats and on a twelve-hour shift. The one-heat technique which eventually superseded this method gave a much greater output: for example, 42 axles of 6 cwt. each in a shift of only 8 hours.

By 1920 a third method was in general use by means of which still higher figures, well beyond 40 per shift, were obtained, even on axles weighing as much as $8\frac{1}{2}$ cwt. It may be of interest to describe the three methods.

Manufacturing Techniques

Method 1.—In this, the oldest, method, the hammer used was of 3 to 4 tons, and was often extremely narrow between the legs, which prevented easy manipulation of the work. The furnace held from 6 to 8 blooms. Half of the axle was forged at one heat, the other end of the bloom being then recharged into the furnace. The dimensions were carefully adhered to, and the surplus material was cut off from the ends under the hammer, which took up a considerable amount of time. Exactitude so great was unnecessary, except in the taper middle, as the axles had to be machined in any event.

Ten minutes were required to forge each half, so that three axles an hour were completed. To heat a furnace full of blooms took from 60 to 70 minutes. These figures varied at the different works, being influenced by the speed of the hammer, and by the time occupied in charging and heating the furnace. It is known that at one works six axles were finished in $1\frac{1}{2}$ hours, whereas at another, $2\frac{1}{2}$ hours were required, both firms working on axles of the same size.

Method 2.—This was a method in which one heat only was required. A 4-ton hammer was used, and the width between the legs was about 13 ft., so that when one half of the axle was finished, the tongs could be slipped on

the finished end and the axle swung round into position for forging the second half. A continuous furnace would hold about 30 blooms, two fresh blooms being charged as every pair of axles was completed.

The surplus on the ends was not cut off, and the wheel seats were forged $\frac{1}{8}$ in. larger in diameter than the finished diameter, the journals being $\frac{1}{4}$ in. larger than the finished diameter. This allowance, more liberal than in Method 1, was not a total loss, but an advantage, since it saved the lives of many axles that disclosed seams and would have been rejected in the machine shop had there been less material to turn off. The time taken to forge one axle was 7 minutes, and at times 8 axles an hour were forged.

The forged axles were laid on a gantry alongside the hammer and carried by overhead crane, six at a time, to gantries alongside the lathes. Here one lathe cut off the two scrap ends and drilled a centre in each end, the time required for this work being 13 minutes. The axle was then laid on a gantry alongside a lathe which rough-turned the journal and wheel seats, finishing 16 axles

a shift. After inspection, the axles were delivered in this condition.

Method 3.—This method calls for a bloom sawn to an exact weight, with merely allowance for a heat waste in the furnace, the axle being forged at one heat. The ends are neither cut off as in the first method, nor left rough as in Method 2, the collar itself being accurately forged by means of a suitably-shaped recess in the top and bottom axle tools. Consequently, there are no scrap ends. The production of axles per shift by this method is exceedingly high, and the axles are not rough-turned before being delivered.

The first patent for a method of manufacturing axles by rolling them was applied for in 1910, but nothing seemed to come of this. In Britain, to-day, steel axles may be made of either acid or basic open hearth material, or of steel made in the electric furnace, but it is laid down in B.S.S. No. 2 of 1941 for locomotive straight axles that while these may be made from ingots rolled to bloom size, they must be finally shaped by forging under a hammer or press.

Fatigue Life as a Function of Surface Conditions

By D. E. Swets and R. C. Frank

Research Staff, General Motors Corporation, Detroit, Michigan

IT has been shown that effects occurring at the surface of a fatigue specimen may have a considerable influence on its fatigue life.¹⁻⁴ The significance of these surface effects was illustrated during some recent work with SAE 52100 steel test specimens. It was noted that specimens which were covered with a surface layer of lubricating oil had a longer fatigue life than specimens that were clean and free of oil. To establish that the longer fatigue life was due to the oil film, twelve fatigue specimens, prepared for use on an R.R. Moore Fatigue Test Machine, were cycled to failure under two controlled conditions. Six of the specimens were fatigued with a

liberal coating of lubricating oil on the surface, and the remainder after thoroughly cleaning their surfaces in acetone and alcohol.

Fig. 1 is a Weibull plot of the data obtained. It can be seen from the figure that the clean oil-free specimens had distinctly shorter fatigue lives than the oiled specimens. All the specimens were tested at the same stress level of 125,000 lb./sq. in. on the same R.R. Moore test equipment. The tests of oil-free and oiled specimens were made in a random order, and since the specimens were selected at random from the original stock of fatigue specimens, it is felt by the authors that the effect noticed was due solely to the surface condition of the specimen. It is interesting that at the stress level used, the clean oil-free specimens usually broke within ten or fifteen minutes, which means that the effect takes place fairly rapidly. This set of tests makes it clear that if one is going to test other parameters on SAE 52100 steel with the fatigue machine, it is extremely important that all specimens must have uniformly oiled or uniformly oil-free surfaces.

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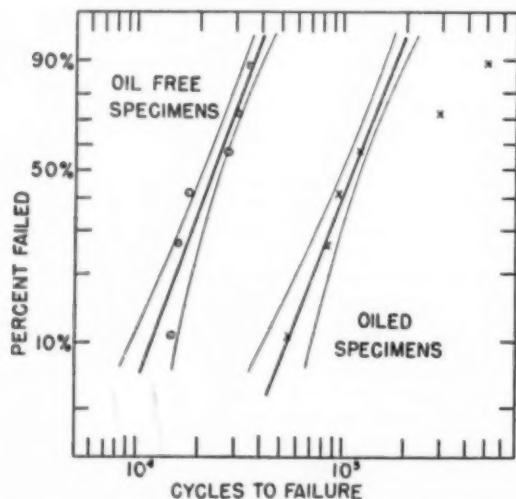


Fig. 1.—Weibull plot of oiled and oil-free fatigue specimens.

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SOUTHERN INSTRUMENTS COMPUTER DIVISION announce that they have appointed Elesco Electronics, Ltd., (associated with Land, Speight & Co., Ltd.), 2 Fitzroy Place, Glasgow, C.3, as their exclusive agents for the whole of Scotland. All Computer Division products will be handled by Elesco Electronics, including the cathode ray polarograph and data reduction equipment.

Hardness and other Physical Properties of Metals in Relation to Temperature

By E. R. Petty, B.Sc.

Hot hardness testing is becoming increasingly significant through its relation to many other metallurgical properties. The object of this paper is partly to support the claim of the test as a tool for high temperature deformation studies. The literature has been reviewed, and the mode of deformation in the "equicohesive range" is discussed and used to explain the form of the hardness-temperature relationship for pure metals. A simple correlation between hardness and creep properties has been shown to exist for a variety of metals.

INDENTATION hardness is not often used in scientific studies, because of the objections that it involves a complicated state of stress and cannot be identified with any one dimensional quantity. In spite of this, the usual hardness values bear a relation to several mechanical and atomic properties, e.g. yield point,¹ tensile strength,² fatigue strength,³ creep and creep rupture,⁴⁻⁶ crystal structure,⁷ compressibility,^{3, 8} ionic radii,⁸ and Lindeman frequency.⁹ It has been correlated with certain electrical and magnetic properties,^{10, 11} and provides a simple but sensitive means of following age-hardening, strain-ageing, recovery and recrystallisation, phase changes,⁷ and isothermal transformation.¹²

Hardness and Melting Point

It has long been noted that, in general, the higher the melting point of a metal the greater is its hardness, but a quantitative analysis of the relation has been obscured by the variations of reported data. Westbrook¹³ has reviewed results for the hardness and melting temperature (T_m) of many pure metals. Newer hardness values for purified metals are included in Table I. Some of the hardness values are probably high; e.g. in the case of osmium, ruthenium and uranium hardness values are reported for the impure and/or as-cast metal. Results for the metalloids germanium and silicon are also quoted, but show no agreement with the metals as they belong to the special diamond cubic lattice type discussed by O'Neill.⁶ The value for face-centred tetragonal γ -manganese¹⁸ is plotted in preference to that of 950 V.P.N. for complex α -manganese. The high value of 240 for plutonium is probably due to its complex crystal structure, which is thought to be of the α -manganese type. The hardness-melting temperature relationship is not linear, and it must be appreciated that room temperature is a purely arbitrary point on the hardness-temperature curve for each pure metal. If log. hardness be plotted against reciprocal absolute melting point, as in Fig. 1, the points fall near to a straight line of equation

$$\log H = 2.3 - 3.1 \frac{T_R}{T_m} \quad (1)$$

where H is the Brinell hardness number and T_R is room temperature (assumed to be approximately 300° K.).

Equation (1) for all metals has its analogy in Westbrook's expression for the hardness-temperature relation of a pure metal (Equation (3) below). A better reference

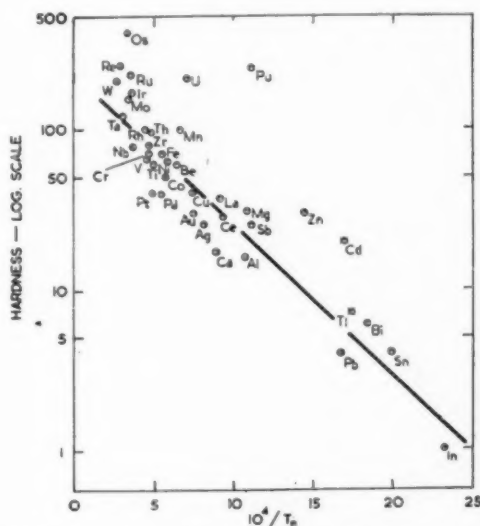


Fig. 1.—Room temperature hardness of various metals plotted against the reciprocal of their melting temperature in °K.

hardness would be that at half the respective melting points on the absolute scale, or, perhaps, at absolute zero. Unfortunately data for the extrapolated "intrinsic hardness" (at 0° K.) are scarce and unreliable. Ludwik¹⁴ and Ito¹⁵ have given some results from which may be calculated the hardness at $0.5 T_m$ (Table I) which, as far as the limited data permit, indicate that there is a linear relation between hardness and T_m for each crystal system.

Westbrook has also reviewed contributions to hardness-temperature relations and concludes that Ito¹⁵ and Shishokin¹⁶ have given the most satisfactory expression, which he writes:—

$$H = Ae^{-BT} \quad (2)$$

$$\text{or } \log H = \log A - BT$$

$$= \log A - k \frac{T}{(T_m)^n} \quad (3)$$

where H is the hardness

T is the temperature of testing in °K.

A is the "intrinsic hardness," i.e. H at $T = 0^\circ \text{K.}$

B is the "thermal coefficient of hardness"

and k and n are constants.

TABLE I.—HARDNESS DATA FOR PURE METALS.*

Metal	Crystal Structure†	Melting Temperature T_m °K.	Hardness H	H at $0.5 T_m$		H at 0°K. A	Hardness Coefficient $-B \times 10^4$
				Ito	Ludwik		
Aluminium	F.C.C.	933.1	16	21.5	26	55.5	1.92
Antimony	Rhombohedral	903.5	25	36	26	115	2.555
Beryllium	C.P.H.	1557	60				
Bismuth	Rhombohedral	544	6	21	16	121	6.46
Calcium	F.C.C.	1123	17				
Cadmium	C.P.H. c/a 1.9	505.9	30	33	23	236	6.63
Cerium	F.C.C.	1073	28				
Chromium	B.C.C.	2133	70			206	0.287
Cobalt	C.P.H.	1765	86.48			213	0.227
Copper	F.C.C.	1356	40	43.5	39	65-117	1.47-1.3
Gallium	Complex	302.8	6-7				
Germanium	Diamond cubic	1232	612 [‡]				
Gold	F.C.C.	1326	180 [§]				
Indium	F.C.Tet.	430	27				
Iridium	F.C.C.	2716	170				
Iron	B.C.C.	1810	67			171	1.94
Lanthanum	C.P.H.	1085	37				
Lead	F.C.C.	600.3	4	6.7	4	35.1	3.54
Lithium	B.C.C.	452	0.5				
Magnesium	C.P.H.	923	30	25.3		99.6	2.92
Manganese	α Complex cubic γ F.C.Tet.	1517	950 100				
Molybdenum	B.C.C.	2883	156			172-323	0.844-1.333
Nickel	F.C.C.	1728	63	27.5		99-107	0.386-1.039
Niobium	B.C.C.	2741	78				
Osmium	C.P.H.	2973	400				
Palladium	F.C.C.	1825	37				
Platinum	F.C.C.	2042	40				
Plutonium	Complex	910	240				
Potassium	B.C.C.	336.6	0.037				
Rhenium	C.P.H.	3453	250				
Rhodium	F.C.C.	2253	100				
Ruthenium	C.P.H.	2773	220				
Silicon	Diamond cubic	1705	750 [‡]				
Silver	F.C.C.	1233.8	25	28.1		35.6-45.4	0.84-1.404
Sodium	B.C.C.	370	0.07				
Tantalum	B.C.C.	3250	70-120				
Thallium	C.P.H.	576	7.3				
Thorium	F.C.C.	2093	35; 95				
Tin	Tetragonal	504.9	4-5	17.5	12	123-135	8.08-9.46
Titanium	C.P.H.	2003	60				
Tungsten	B.C.C.	3653	200			349-510	0.627-1.464
Uranium	Orthorhombic	1403	210				
Vanadium	B.C.C.	2193	65 \pm 10				
Zinc	C.P.H. c/a 1.9	692.5	30	48	28	128-263	2.73-4.92
Zirconium	C.P.H.	2135	75-90				

* Sources include: Metals Handbook A.S.M., 1948; C. J. Smithells "Metals Reference Book," 1955; D. Tabor, "Hardness of Metals," 1951. Values for A and B are taken from Westbrook.¹³

† F.C.C. indicates face-centred cubic; B.C.C. indicates body-centred cubic; C.P.H. indicates close-packed hexagonal; F.C.Tet. indicates face-centred tetragonal.

‡ Private communication from Dr. G. A. Geach to Professor H. O'Neill.

§ Micro-lirnel (Geohart, R., *Zeit. Metallkunde*, **34**, 1942, 255).

¶ The value of 5-47 given by Westbrook seems erroneous.

Thus, when $\log. H$ is plotted against the test temperature for a pure metal, a straight line results. Actually, two separate straight lines are observed which intersect near $0.5 T_m$ (Fig. 2). The slope B and constant A have therefore two values each, one above $0.5 T_m$ and another below.

The logarithmic relation is probably fundamental, as Hollomon and Lubahn¹⁷ have shown that the logarithm of the flow stress of metals is a linear function of temperature at constant strain and strain rate.

Interpretation of Hardness-Temperature Relation

Westbrook¹³ has attempted an analysis of the constants A and B which will not be repeated here.

The break at $0.5 T_m$ could be due to

- a change in state or structure;
- a characteristic of the method of plotting; or
- a change in the deformation mechanism.

Obviously all metals do not have a transformation of crystal lattice at $0.5 T_m$, and the inflection differs from that due to allotropy as can be seen in Fig. 2 for manganese.¹⁸ At 450°C . ($0.48 T_m$) the inflection is observed while the other discontinuities at 700° , $1,100^\circ$, and $1,133^\circ\text{C}$. are due to allotropic transformations. The other effects that temperature has on metals are recovery, recrystallisation and grain-growth. Smith and

co-workers¹⁹ suggest that constant B is different at temperatures above the inflection due to rapid crystal recovery. They arrive at this conclusion, after showing that steels treated in moist hydrogen to remove carbon and nitrogen (and hence strain-ageing), behave like a pure metal in their hardness-temperature relation, and that the change in slope of the straight lines occurs at the temperature where relaxation is known to be rapid.

Deformation at low temperatures occurs by a process of slip along preferred planes and directions in the crystal, usually the planes of greatest atomic density, e.g. (111) in the face-centred cubic lattice. At high temperatures deformation can occur by the following three processes:—

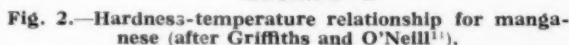
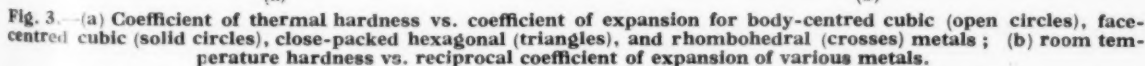
- slip along more than one plane and direction, due to increased atomic mobility²⁰;
- Mott's concept²¹ of dislocation climb: this entails the climbing of "stuck" dislocations from one plane to another over potential barriers, and the continued movement of them to form a continuous "wall of dislocations," i.e. a polygonised grain; and
- grain boundary rotation^{22, 23, 24}.

Hollomon and Lubahn¹⁷ have shown that in hot tensile tests at constant strain and strain rate, the plot of $\log.$ stress against temperature is linear (*cf.* hardness).

Pugh²⁶ gives the following semi-quantitative expression allowing for both types of deformation :—

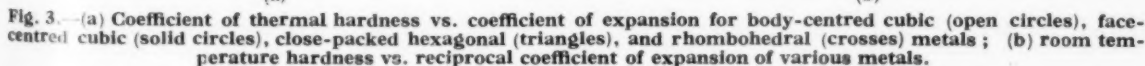
where H_B is the Brinell hardness
 G is the elastic shear modulus, kg./sq. mm.
 b is the Burgers vector Å
 T is the test temperature °K.
 t is the time of loading
and c is a constant depending on crystal structure.

At low temperatures the thermally activated processes play a minor role, but at the higher temperatures they



It has recently been shown²⁹ that the activation energies for creep of single crystals and of polycrystals are identical, and also that they compare well with the activation energy for grain-boundary shear, which suggests that this is a mechanism of creep. This point is further discussed in the section on creep.

As the temperature of a metal increases, so it simultaneously expands and softens. It seems likely that the more rapidly it expands the more quickly it will soften.



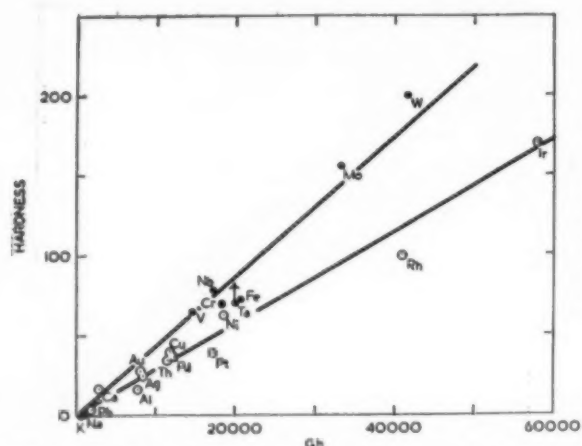


Fig. 4.—Hardness vs. force (Gb) required to move a dislocation through the lattice of body-centred cubic (solid circles) and face-centred cubic (open circles) metals.

due to the increasing atomic spacing.⁸ The rate of softening is given by B of Westbrook's equation (2), and this is plotted against the coefficient of thermal expansion for the metals where data are available in Fig. 3a. The results indicate a close relationship, probably linear, between the two factors, but different for each crystal system. Fig. 3b shows the relation between room temperature hardness and the reciprocal of the coefficient of expansion. The smooth curve confirms Edwards³⁰ idea that expansion is a factor in softening.

Hardness and Creep

Correlations between hot hardness and creep rupture tests have been reported in various commercial alloys⁴⁻⁶. The practical advantages of replacing creep rupture tests with the quick and simple hardness test for the sorting of materials into those with good or bad creep resistance are obvious; unfortunately the interpretation of the limited available data is not so obvious.

Garofalo, Malenock and Smith⁶ have shown an excellent straight line relation between hot-hardness and ultimate tensile strength of steels at elevated temperatures. Larson and Miller³¹ have drawn "master curves" of stress against a temperature-compensated time parameter, $T(20 - \log t)$, and have shown that results for hot tensile tests fall on the same curve as creep rupture tests. There must therefore be a relation between hot hardness and creep rupture. Underwood, in the Discussion of reference 19, has realised this correlation for pure

TABLE II.—ACTIVATION ENERGIES FOR CREEP AND SELF-DIFFUSION OF PURE METALS.

Metal	Activation Energy (k. cal./g. mol.)		Metal	Activation Energy (k. cal./g. mol.)	
	Creep	Self-Diffusion		Creep	Self-Diffusion
Aluminium ..	30	33	Molybdenum	120	
Beryllium ..	65		Nickel ..	65	67
Bismuth ..		31	Niobium ..	75	
Cadmium ..	22	17.3	Platinum ..	55	
Cobalt ..		71	Potassium ..		9.1
Copper ..	44	48	Silver ..		46
Gold ..	30	53	Sodium ..		10.5
Indium ..	16.5	17.9	Tin ..	21-23	
Iron ..	78	77	Titanium ..	60	
Lead ..	28	25	Tungsten ..		142; 140
Lithium ..		9.8	Zinc ..	26	20.4; 31
Magnesium ..	31	32-33			

Values are from Dorn³²; Wiseman, Sherby and Dorn³³; Kubaschewski, *Trans. Faraday Soc.*, **48**, 1950, 713.

iron-base alloys, and this is probably the most practicable method of correlation to date.

The simplest approach to the problem would seem to be an attempt to relate the hot hardness and creep results of pure metals, but this does not seem to have been dealt with in the literature. As a theoretical starting point, one might plot the various hardness values against some criteria of creep. One such criterion might be the force Gb (equation (4)) required to move a dislocation through the lattice of the pure metal, which is a measure of the plastic flow stress. Pugh²⁶ has shown that for metals of melting point above 1,000° C., the thermally activated processes can be ignored at room temperature, when equation (4) becomes

$$H_b = \frac{Gb}{c}$$

where c is a constant for each crystal type. Room temperature hardness has been plotted against Gb for cubic metals in Fig. 4, and suggests a linear relation between hardness and other deformation tests. Another criterion might be the activation energy for creep (ΔH_c) which appears in the creep equation³²

$$\epsilon = f(te^{\Delta H_c/RT}) \quad (5)$$

where ϵ is the creep strain

R is the universal gas constant

t is the time of test

and T is the temperature in ° K.

It has been stated³⁵ that the room temperature hardness of a metal does not give much of a clue to its strength at elevated temperatures, nevertheless a comparison of room temperature hardness and the activation energy for creep, ΔH_c , shows an interdependence of the two (Tables I and II).

A more fundamental treatment will reveal that, since indentation hardness is proportional to the reciprocal of the square of the impression diameter, and plastic flow (either under an indenter or in a creep test) would be proportional to the creep strain, then

$$d \propto f(\text{creep strain})$$

$$\text{or } d \propto f'(e^{\Delta H_c/RT}) \text{ for a constant time of testing}$$

$$\text{or } \frac{1}{d} \propto f''(\Delta H_c)$$

$$\text{i.e. } \sqrt{H} \propto f''(\Delta H_c)$$

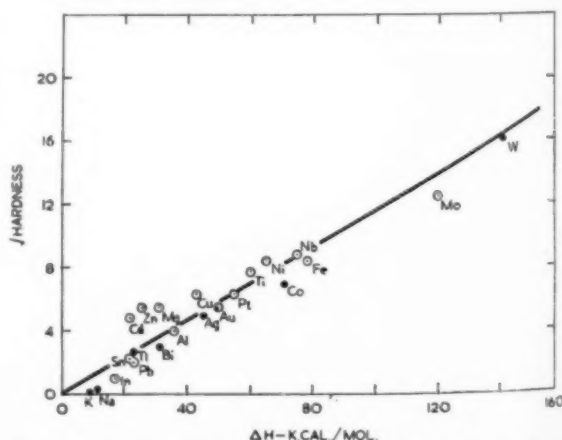


Fig. 5.—Square root of the hardness vs. the activation energy for creep (open circles) and self-diffusion (solid circles) of various metals.

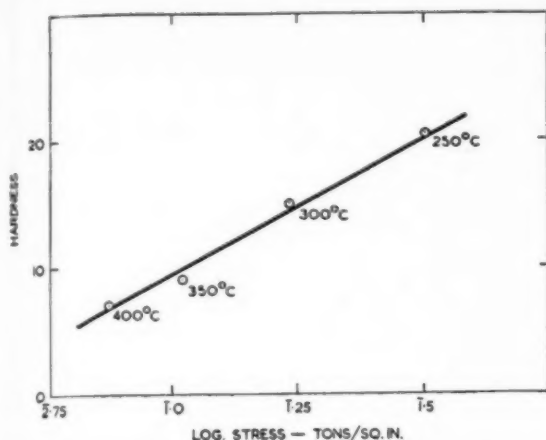


Fig. 6.—Hardness of pure aluminium vs. log. stress to give 10% deformation in 100 hours at the same temperature.

A plot of square root of hardness *vs.* ΔH_s is given in Fig. 5, for a wide range of metals. As has been shown by many workers, and summarised by Dorn²⁵ the activation energy for creep of pure metals is identical with the energy for self-diffusion, and values of this quantity have been included in the graph. The straight line through the origin in Fig. 5 is all the more surprising when it is realised that, whereas hardness is a structure sensitive property, being affected by cold-work, grain size, minor alloying elements, and, above all, temperature, ΔH_s is unaffected by any of these.³² If, instead of the room temperature hardness, a more fundamental property were used, say, hardness at $0.5T_m$ or at 0°K. , better correlation would undoubtedly exist, but clarification of the situation awaits more accurate figures.

Another hardness quantity which might appear to be associated with the creep rate, would be the thermal coefficient of hardness B ; the more quickly a metal softens with rising temperature, the greater the creep rate, i.e. the lower the value of ΔH_s . If the latter were plotted against more reliable values of B , the relation would no doubt be linear, with a different slope for each crystal type. However, for high temperature creep, crystal structure would probably be less important, and Sherby and Lytton³³ suggest that creep rate at high temperatures is governed by crystal structure only to the extent that the diffusivity of the atoms is affected. They conclude that Chubb's findings⁷ that the open packed structures are weaker, are easily understood from this viewpoint, since self-diffusion, and therefore dislocation climb, would occur at a greater rate.

Creep in polycrystalline aggregates has been shown by McLean³⁴ to occur by the migration of dislocations (resulting in slip) and simultaneously by grain-boundary shearing. The activation energy for both processes is identical with that for self-diffusion, and with the activation energy for creep-rupture. These facts support the hypothesis that micro-cracks form by a process of diffusion of vacancies to give aggregates at certain places, usually grain boundaries.

Concerning a practical method of correlating creep and hardness, a lot of work remains to be done on pure metals as well as complex, or even simple, alloy systems. While the practical significance of the alloy work of Bens⁸ and Smith and co-workers⁶ is apparent, a correla-

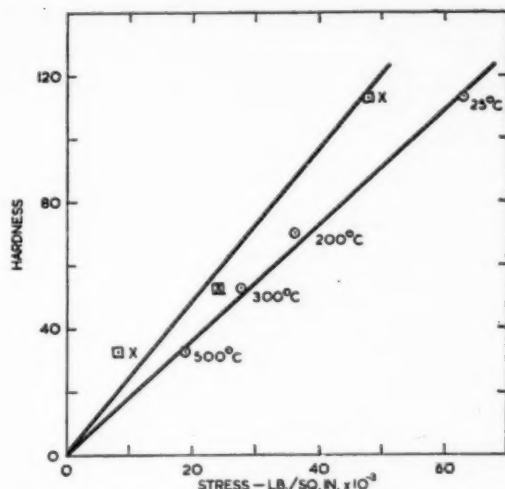


Fig. 7.—Hot hardness of arc-melted zirconium vs. hot tensile strength (circles), 1,000 hr. creep rupture (crosses), and stress to give creep rate of 10^{-5} in./in./hr. (squares).

tion might be more easily understood by starting work on simple pure metals.

There is a paucity of results on creep and creep rupture of pure metals, making generalisations impossible at this stage, but the graphs from Figs. 6-8 show a smooth relation between hot hardness and creep rupture.

Results for hot hardness¹⁴ are plotted against the stress to give 10% deformation in 100 hours²³ (log. scale) for pure aluminium in Fig. 6. A simple relation is seen to exist even though Ludwik's results for hot hardness are not for such high purity aluminium.

The hot hardness of arc-melted zirconium³⁵ is plotted against hot-tensile strength and 1,000-hour creep rupture strength³⁶ in Fig. 7, and shows good approximation to a straight line.

Results of hot hardness and 100-hour rupture strength for molybdenum and a molybdenum-0.5% titanium alloy given by Semchyshen and Torgerson,³⁷ have been plotted as straight lines in Fig. 8. The curves for hot-hardness *vs.* log. stress are equally good straight lines

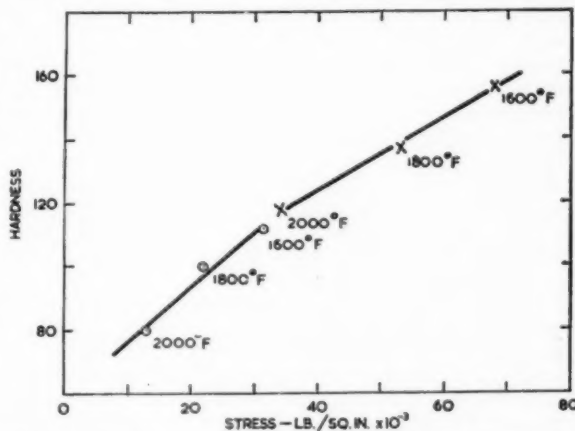


Fig. 8.—Hot hardness vs. 100 hr. rupture strength of strain-hardened molybdenum (circles) and rolled molybdenum 0.5% titanium alloy (crosses).

over the temperature range quoted, but once again data are limited.

The conclusion which must be reached is that a correlation is possible for all pure metals, and probably also for simple alloys, but the complex age-hardening type would not conform easily, if at all.

Acknowledgment

The author wishes to express his gratitude to Professor H. O'Neill in recognition of his constant encouragement and advice, and much invaluable discussion.

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Sixth Coal Science Lecture—"From Coal to Coke"

THE Coal Science Lectures of the British Coal Utilisation Research Association were established in 1951, "as a symbol of the belief that true advances come only from patient enquiry into fundamental principles, and as a recognition of the need to apply recondite researches to practical needs." The sixth in the series of these lectures, delivered in London on October 16th, illustrated the relevance of these statements. The speaker was M. Raymond Cheradame, Technical Director General of the Centre d'Etudes et Recherches des Charbonnages de France (CERCHAR)—the research organisation of the nationalised French coal industry—and the lecture title "From Coal to Coke."

M. Cheradame's address reviewed the difficulties that the French have encountered in using certain of their indigenous coals for the production of metallurgical coke, and dwelt more particularly upon the efforts that CERCHAR has made to solve them. The major part of France's iron ore occurs in Lorraine, where there are also considerable reserves of coal. Unfortunately, the iron ore native to the area is poor in quality, and requires large, strong coke for its satisfactory treatment in the blast furnace. M. Cheradame pointed out that the coals of the Lorraine field are, by nature, unsuitable for the production of such a large, strong coke and that although the Lorraine collieries had been making coke for a long time this was so small and friable that it had been confined to the domestic market. To meet the needs of the steelworks it had been the practice for coke to be imported from the Ruhr or, alternatively, for coking coals to be purchased in order that they might be mixed with Lorraine coals to give the properties demanded of a metallurgical coke.

Clearly then, it was an urgent and fundamental problem for the French to find means to produce a satisfactory metallurgical coke from the highly swelling coals of Lorraine, and it was to this problem that CERCHAR addressed itself afresh in 1950 when a new programme of research was initiated. Prior to this date the work of CERCHAR had been confined largely to a scientific study of the fissuring of coke during its formation, little attention being given to the direct

improvement of the large-scale coking process. Since 1950, however, the basic researches carried out in the Verneuil Laboratories of CERCHAR, both in laboratory apparatus and small ovens treating up to 20 kg. of coal, have been supplemented by practical tests on full-scale ovens erected for experimental purposes at Marienau in the Lorraine coal basin. These test ovens are under the direct control of CERCHAR, an arrangement which permits a close correlation to be attained between research techniques and practical experience.

Turning to a more detailed review of the fundamental researches recently undertaken at Verneuil, M. Cheradame described a method by which the fissuring of a single coal on heating and cooling could be examined by observation with X-rays. This method could be combined with the use of a cine camera, taking one frame per 30 seconds, to observe the progress of the plane of fusion, the plane of resolidification, and the development of fissuring. It was confirmed that a study of the mechanical variations of the solid in the complete interval between resolidification and the termination of heating was necessary, and a Joumier dilatometer was adopted for the purpose. The records made with this dilatometer showed the progressive contraction of semi-coke from 500° to 1,000° C., and also the variation in the rate of contraction. The contraction rate, which depends on temperature, starts from a maximum at resolidification, the maximum having a very different value for a good coking coal and a Lorraine coal.

It was observed that, for a thin slice of coal, the difference of the contraction rates due to the temperature differential induced only curvature. On a thicker slice the curvatures that the various layers wanted to assume were not compatible; there were, therefore, some residual contractions or expansions that induced tensions growing with the thickness, eventually reaching the breaking point. Some fissures were then produced perpendicular to the plane of heating.

In parallel with these observations a mathematical analysis of the phenomena made it possible to describe the relation of cause and effect in fissuring in more

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Vacuum Melted Steel

Commercial Scale Production in Sheffield



General view of vacuum melting installation.

A CEREMONY of particular interest and significance took place on October 3rd, when Sir Frederick Pickworth, the Master Cutler, opened the new High Vacuum Metallurgical Department of G. L. Willan, Ltd. This department, with its high frequency vacuum melting furnace, is one of the first in the country to offer special high duty steels made by this process on a commercial basis. The process itself is not new—research has been carried out on it for many years—but vacuum melted steel has not previously been put on the market. This development will be of special interest to those industries requiring such high duty steels, particularly aircraft and nuclear engineering.

The company was incorporated in 1952, being launched by Mr. G. L. Willan, the present chairman and managing director, who provided most of the initial capital. Mr. Willan received his metallurgical education at Sheffield University and subsequently spent five years in the steel industry in South Wales. He joined Electric Furnace Co., Ltd., in 1937, and as metallurgist he was stationed in Sheffield, later becoming Northern area manager. Since 1952, Mr. Willan has been concerned almost solely with the establishment of G. L. Willan, Ltd., as a steel and alloy manufacturing concern, which today retains its independence of outside control.

The company was originally formed with the object of purchasing and operating a new 150 kW. high frequency melting installation designed to work in conjunction with one 5 cwt. and one 10 cwt. furnace body. The aim at that time was to manufacture a range of tool and alloy steels, and at the same time to undertake hire melting of ingots for the Sheffield trades. During the first two years, the company experienced considerable difficulties, mainly attributed to insufficient working capital and the problems of finding adequate quantities of work to maintain production on an economic basis. Some three years ago, however, the company commenced the production of special alloys, mainly in the form of melting stock for use by precision casting foundries, the majority of which were either part of, or associated with, aircraft engine manufacturers. In this connection, the company developed a successful special

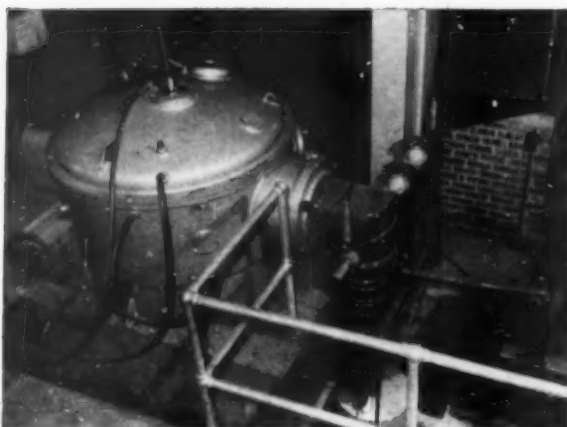
process for the manufacture of remelt cast bar in a very wide range of alloy specifications. This work was carried out under A.I.D. control, approval being granted to the company in 1954.

After initial trials, the aircraft industry gave the company every encouragement to proceed with its production, and during the last three years the expansion has been very rapid. In 1955, demand exceeded capacity, and a decision was made to transfer the melting plant from the original Furnival Road Works, to the larger premises now occupied in Sussex Street, and also to install a second high frequency installation of similar rating and capacity to the first. A third 200 kW. installation is now nearing completion, and should be in production shortly. With a labour force of approximately 80, some 45 tons of steel and alloys are produced each week, including a balanced proportion of ingots and cast bar work.

Some 18 months ago, a decision was made to proceed with the installation of a 56 lb. high frequency vacuum melting furnace, as at that time it was apparent to Mr. Willan that although considerable interest was being taken throughout the country in the metallurgical potentialities of vacuum melted material, there existed outside America and Russia very little vacuum melting equipment to provide metal on which development work could be carried out. The prime interest was, of course, centred on vacuum melted stock for remelting by the precision casting foundries. Early in 1956 a 50kW. 56 lb. capacity melting installation was ordered from the EFCO-Edwards Vacuum Metallurgical Co., Ltd., and a new 40 ft. span by 75 ft. long building was erected to house this equipment. Preliminary melting trials were carried out during the week commencing June 17th, 1957.

Vacuum Melting Equipment

The furnace unit and mould are housed in a 3 ft. 9 in. diameter vacuum chamber constructed from mild steel plate. There is a horizontal dished cover at the top and a similar dished closing plate at the bottom. The lid and the upper part of the vacuum chamber are fitted with water jackets to minimise the heating effected by



View of the vacuum chamber and pumping equipment.

radiation: the lid is designed for lifting by block and tackle. As a safety precaution, the chamber is fitted with a spring-loaded explosion port.

The furnace unit is carried on a non-magnetic steel casing. The high frequency coil is of normal construction, but the associated Efcnite supports are heat treated and, where necessary, vacuum impregnated to obviate any need for outgassing. The refractory lining can be rammed by conventional methods.

"From Coal to Coke"

(Continued from page 236).

precise terms. The fissures that are produced are spaced out at an interval which is inversely proportional to the coefficient of contraction of the coke soon after its resolidification, proportional to the permissible extension of the coke before rupture in the range 500° to 700° C., and inversely proportional to the thermal gradient in that range.

Another avenue of research explored at CERCHAR and discussed by M. Cheradame was the investigation of the carbonisation of blends of two fusible coals. He described how blends of different proportions of a good coking coal and a "flaming" coal with high volatile matter behaved when carbonised. From the experimental results obtained by CERCHAR he was able to deduce two rules for the utilisation of fusible coals in industrial blends. These were (1) that their anti-fissuring "efficiency" is greater the higher the temperature of resolidification, and (2) that the richer in volatile matter and the less fusible the "flaming" coal, the more fusible and rich in volatile matter had to be the coal mixed with it.

He then discussed the relative efficiencies of coke dust and chars as inert additives in blends, and reviewed the work done on blends containing non-fusible coals. He pointed out that inert additives needed to be substances that did not contract much in the region of resolidification, with the result that the mean contraction rate became less. On the other hand, at higher temperatures, there were bound to be stresses due to relative contraction of coal and inert constituents.

The reactivity of coke has been selected by CERCHAR

Internal charge feeders are available for making additions, during melting, of up to a third of the total charge. There is also a small additions feeder giving random choice of six different materials. A substantial mould platform is provided inside the furnace chamber with provision for connecting a water-cooled copper mould if required.

Ancillary equipment includes a poker with sampling stick attachment and immersion pyrometer for measuring the temperature of the melt.

The high frequency system is completely isolated from the vacuum chamber. It consists of a motor-generator set, bank of capacitors, and a control panel with instruments and switches to vary the number of capacitors in circuit. An Efeo-Metrovick pattern earth leakage relay will switch off the power in the event of a crucible lining failure, and give warning when the lining thickness is reduced to danger point.

The power requirements of the installation are 50 kW. for the furnace unit and 14 kW. for the pumps and equipment: this is supplied at 380-440 V., 3-phase, 50 cycles. The high frequency control gear operates on a 200-250 V., single-phase, 50 cycle supply.

The vacuum pumping system comprises a 100 cu. ft./min. Model GKD 110 air ballast rotary backing pump and a Speedivac Model 18B3 vapour booster pump. Pressures in the vacuum chamber and pumping system are measured by two gauges: (a) a Pirani type unit for pressures from 10 mm. to 5×10^{-3} mm. of mercury; and (b) an Edwards Philips type cold cathode ionisation gauge for pressures lower than 5×10^{-3} mm. of mercury.

for study in its future programmes of fundamental research, and in this connection the Centre has already developed an original technique by means of which it is possible to measure reactivity to CO_2 at temperatures of 1,200° C., 1,300° C. and 1,400° C. These reactivities appear to correlate reasonably well with the performance of foundry cokes; some other properties, such as porosity, have been measured in various ways during the course of the same work.

Experiments on the battery of ovens at Marienau commenced with attempts to adapt the Carbolux process to the production of metallurgical coke. It was found, however, that the good coke produced at Marienau was not reproduced when the adapted process was used at a large steelworks, and this was considered to be due to the difference between the care surrounding a research test—even on full-scale plant—and the conditions, including coal deterioration, that are characteristic of industrial coking practice. From the Carbolux process attention at Marienau was turned to the application of blending and increased charging density, and good results have been obtained from these investigations. Among factors studied, in addition to those already mentioned, are dry and moist charging, oven width and the particle size distribution in the charges.

In M. Cheradame's view, three main ideas would dominate future research on coking. These were, first, that the chemical use of hard coal in the form of metallurgical coke should be developed, second, that anthracite and, more generally, smokeless fuels should be used for solid fuel domestic heating and, third, that the range of coals which could be coked corresponded, in many countries, to too small a proportion of coal output, and should be extended.

Properties of Materials at High Rates of Strain

By K. N. Leibovic, B.A., B.Sc.

The behaviour of materials under the novel and arduous conditions of service to which they are subjected in many modern applications has stimulated the detailed study of subjects like fatigue and properties at high rates of strain. The attention paid to the latter topic is exemplified by the recent conference at the Institution of Mechanical Engineers on which this article is based.*

SOME people have gone so far as to suggest that most engineering design problems are now solved, and that further progress will be made by a better understanding and improvement of the properties of materials. Be that as it may, and many are not convinced that perfection in design has been achieved even in theory, there is no doubt of the importance of the study of properties of materials to further progress in many branches of engineering.

The effect of subjecting materials to high rates of strain are interesting and often unexpected from a knowledge of their static behaviour. Moreover, these effects are of much practical importance as they arise in metal working operations, (punching, strip rolling, wire drawing, etc.), and in engineering structures or components such as turbine blades, high speed aircraft, projectiles and parts subjected to explosive deformation.

Propagation of Stress Waves

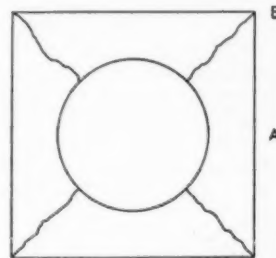
At high rates of strain, the behaviour of a solid is governed by the manner in which deformation is propagated, rather than by the static stress-strain relationships. It has been said that at high rates of strain one part of the body often does not know what is happening to another before being overtaken by events. To put it differently, a material reacts to a stress by yielding and strain-hardening: such reaction is rapid, but if the stress is transmitted with very high speed there may be insufficient time for the material to accommodate itself to the load in the usual way.

Stresses are transmitted by means of waves. Hence the study of wave propagation is of prime importance: two examples may be given to illustrate the effect of stress waves. Firstly, suppose a long bar is struck a compressive blow at one end: the compressive wave travels through the bar and when it reaches the other end it becomes a tensile wave; failure may then occur through tension at this end. Secondly, consider a square bar of material with a circular hole drilled centrally along its length, as shown in Fig. 1, and suppose an explosive charge is detonated inside the hole. It has been demonstrated that failure takes place along a diagonal, as shown at B, and not at the weakest part A as might be expected. This is due to the trapping and reflection of waves in the corners which build up to very high stresses there.

Elastic and Plastic Strains

A material which may be elastic at small deformations often becomes plastic at higher strains, and both elastic and plastic waves occur in different materials and under

Fig. 1.—Mode of failure of square bar as a result of detonation of explosive charge inside axial cylindrical hole.



varying conditions of strain. Plastic behaviour may be the result of exceeding the yield strength; or it may be due to intense local heating and softening of the material and its inability to conduct away the heat sufficiently quickly. This can even occur at extremely low temperatures and under slow straining. Thus² the plastic stress-strain curve of aluminium at 4.2° K. has a serrated appearance indicating sudden drops in the load which then rises again slowly. It has been shown that this is due to reversible adiabatic softening: the applied load raises the temperature of the aluminium and plastic flow sets in with a resulting drop in the load. This, in turn, allows the specimen to cool and become stronger, so that the load is increased. The process is then repeated all over again. The apparently high rise in temperature is due to the small specific heat at these low temperatures. In addition, plastic flow is aided by the rapid lowering of the yield stress in aluminium as the temperature approaches absolute zero.

Effect of High Strain Rate on Yield and Fracture

A number of competing effects are met at high strain rates, and the result on the material depends on the balance of these effects under working conditions. For example, the competition between thermal softening and strain hardening has been shown³ in many cases to lead to initial increase and subsequent falling off in yield stress.

The effect of high strain rates on the yield of a wide range of materials may be summarised in three statements:—

- (1) The greater the loading rate, the greater is the ratio of dynamic to static yield stress.
- (2) The greater the static yield, the less the strength is enhanced by rapid loading.
- (3) A stress greater than the static yield stress,

* A short review of fatigue which formed the subject of an international conference at the Institution of Mechanical Engineers has been published elsewhere.¹



Fig. 2.—Edge dislocation.

suddenly applied and held constant, will give enhanced strength and a delay time before rapid yielding sets in. This delay time depends on the material as well as the load.

In practice it is of great interest to be able to predict damage due to varying rapid impulse loading. There is experimental evidence that the amount of damage at any stress is proportional to the fraction

$$\frac{\text{time at that stress}}{\text{yield delay time}}$$

and yield occurs when the sum of such fractions is unity.⁴

One consequence of yield delay is the brittle fracture under dynamic loading of materials which have great ductility under static loads. A case in point is Durestos⁵, which consists of asbestos fibre in a matrix of phenol formaldehyde resin and is used in aircraft structures.

Fundamental Theory and Experiments

It should not be thought that the effects of high strain rates must be associated with large numerical values of stress or strain and their rates of change. It is only necessary to recall the Weissenberg effect, i.e. the tendency of some fluids to climb up a rotating shaft, in order to realise that small forces may already give rise to these effects. A strain rate which will be considered low in one material may be high in another. A high strain rate, then, is one which will produce a behaviour radically different from that observed under static loading.

As may be expected, a great deal of attention has had to be devoted to the design of suitable experiments and apparatus to measure the effects of high strain rates, and much theoretical work has been done on basic theory and the analysis of results.

Modern dislocation theory is fundamental to the understanding of the molecular processes involved, and has had much success, e.g. in providing criteria for

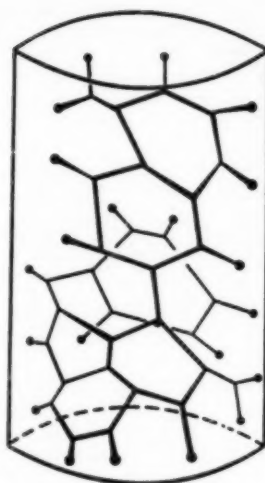


Fig. 3.—A dislocation network in a crystal.

yield and fracture. As is well known, the strength of actual materials is much lower than would be expected from a knowledge of inter-atomic forces in a perfect crystal lattice. This is explained by showing that the crystal structure is not perfect in practice but that it contains dislocations (see Fig. 2), due to the process of crystal growth, which weaken the crystal. These dislocations are generally arranged like a 3-dimensional network of lines (see Fig. 3) with each line representing one dislocation². When subjected to stress, an activation energy is provided for this network to generate new dislocations. Based on this, a criterion for dynamic yield can be deduced such that⁶

$$\int_0^{\tau} \exp(-U/kT) \cdot dt = C$$

where τ is the time to yield, U is the activation energy for the release of a dislocation (which depends on the applied stress), k is Boltzman's constant, T is the absolute temperature, and C is a constant.

Slip in crystal planes is explained by the movement of dislocations, and is facilitated by the process in which the primary dislocations generate large numbers of secondary dislocations (see Figs. 4 and 5), which appear as slip lines or bands in a metal. The movement of

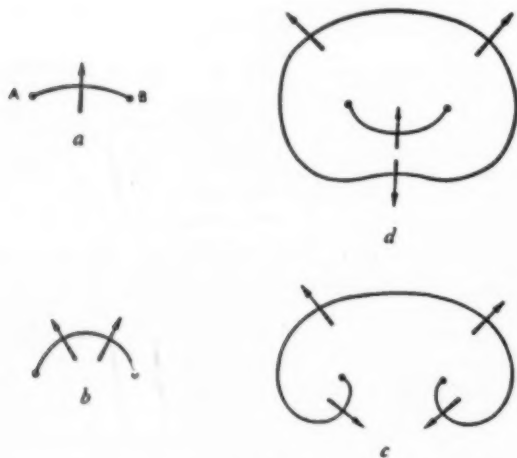


Fig. 4.—Stages a, b, c and d in the formation of a dislocation ring from a Frank-Read source AB.

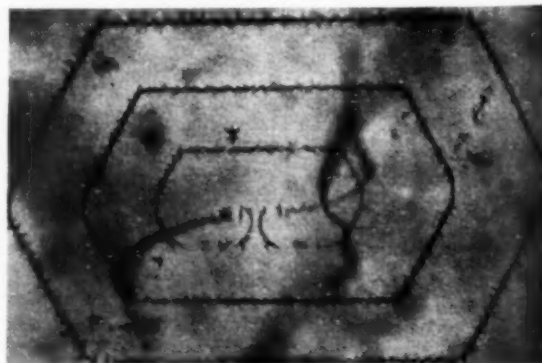


Fig. 5.—A Frank-Read source in operation in silicon at 900° C. The dislocation lines are revealed by small precipitates of copper. The outermost loop is about 0.3 mm. wide.

these dislocations is governed by the applied stresses as well as by the stresses due to the internal fields of force and obstacles such as grain boundaries or other dislocations piled up at barriers in the material. When the applied stress is less than the internal stresses, the material is elastic, but when it exceeds the internal stresses, plastic flow occurs. The effect of plastic flow is to relax possible excess stresses and protect the material from overloads even under shock loading.

The internal field of force may be of long or short range, depending on the material. Since thermal energy fluctuations in solids are of rather short range, it follows that the effect of temperature will be pronounced in those materials which have short range internal force fields, and less effective in those which have long range fields. This explains the fact that materials like copper, nickel, austenitic steel, and to some extent also aluminium, remain "tough" at low temperatures. On the other hand, mild steel with its pronounced yield delay and dependance on strain rate, has short range internal forces—it is ductile at ordinary temperatures and becomes brittle at low temperatures.

The dislocations which give rise to slip and yield will also produce fracture, due to the stress concentrations in piled-up groups or the coalescence of dislocations which open up a crack. The conditions under which either fracture or yield will be expected have been investigated, and it has been shown² that if the effects of thermal agitation are neglected, i.e. at very low temperatures, fracture results when the applied stress is of higher order than

$$\sigma = \mu(b/d)^{1/2}$$

In order to start a slip band, a certain average stress σ_s is required at dislocations. The slip band runs along until it meets an obstacle such as a grain boundary. The ends of the slip band set up stresses in the material, and hence a pile-up of slip bands will set off further yielding or fracture. Yield will occur in preference to fracture if

$$\sigma_s < \mu \left\{ \left(\frac{b}{l} \right)^{1/2} + \left(\frac{b}{d} \right)^{1/2} \right\}$$

where μ = shear modulus

b = a length of the order of inter-atomic distances

d = grain diameter

l = spacing distance of dislocation network.

It should be noted that the first of these equations refers to the mean stress in the material, and the second to the average stress at a source of dislocations which is required to trigger off this source and start a slip band.

The first of these equations shows that breaking strength can be increased by reducing the grain size, and from the second equation it is seen that ductility at low temperatures can be increased by either reducing the scale of the dislocation microstructure or by reducing the grain size. In fact it has been demonstrated⁷ that reduction in grain size from 4×10^{-3} cm. to 6×10^{-4} cm changed iron from brittle to ductile at 4.2°K .

At elevated temperatures, due to thermal agitation, the movement of dislocation lines is facilitated. This results in easier yielding and after a certain temperature, called the transition temperature, is passed, yielding and ductility will replace brittle fracture. The transition temperature is sensitive to rate of strain because the yield delay time increases as the temperature is reduced. Thus for coarse-grained iron, the transition temperature

may vary between 90°K . and 300°K ., depending on the rate of strain.

Conclusion

Active interest in the properties of engineering materials at high rates of strain is of relatively recent origin. The rapid progress which has been achieved in this subject is largely due to the happy co-ordination of theory and practical application. A deeper understanding of the processes involved leads to better design, using existing materials, and points the way to the development of new materials with improved characteristics.

Acknowledgment

Acknowledgment is made to the Institution of Mechanical Engineers for permission to reproduce Figs. 2-5, which appeared in a paper presented by Dr. A. H. Cottrell, F.R.S. to a Conference on the Properties of Materials at High Rates of Strain earlier this year. Fig. 5 was reproduced in Dr. Cottrell's paper by permission of the American Institute of Physics.

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Meeting Diary

(Continued from page 214).

28th November

Institution of Engineering Inspection, North Western Branch. "Argonarc and Argonaut Welding," by R. BLACKBURN. Engineer's Club, Albert Square, Manchester. 7.30 p.m.

Iron and Steel Institute. Hatfield Memorial Lecture. "The Mechanism of the Formation of Banded Structures in Steel," by PROFESSOR P. BASTIEN. Firth Hall, University of Sheffield. 6.30 p.m.

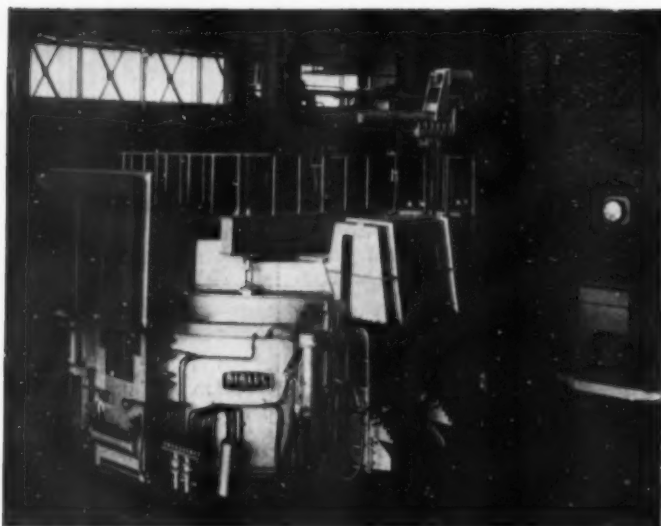
Sheffield Metallurgical Association. Joint Meeting with the Iron and Steel Institute and the Sheffield Society of Engineers and Metallurgists. 2.15 to 3 p.m. "Heat Flow in Ingot Hot Tops," by G. FENTON, "Studies on Ingot Feeder Heads," by H. S. MARR and W. H. GLAISHER; 3.45 to 4.25 p.m. "Low Temperature Impact Properties of Cast Steel," by W. J. JACKSON and G. M. MICHIE; 4.25 to 5 p.m. "High Boron Alloy Steels," by T. H. MIDDLEHAM, J. R. RAIT and E. W. COLBECK. Metallurgical Lecture Room B.1, The University, St. George's Square, Sheffield. 2.15 p.m.

29th November

Institution of Mechanical Engineers. "Recent Developments in the Manufacture of Castings," by J. L. RICE, R. W. RUDDLE and P. A. RUSSELL. 1, Birdcage Walk, London, S.W.1. 5.30 p.m. for 6 p.m.

New Aluminium Powder Plant

A. WIGLEY (BELPER), LTD., of Horseley Woodhouse, Derbyshire, aluminium smelters and ingot manufacturers announce that their associated company, North Derbyshire Metal Products, Ltd., of the same address, has commenced operation as manufacturers of aluminium powder. A new plant has been erected employing the most modern methods of building construction, and special equipment is available for the production of air blown aluminium powder, which is offered in a range of grades.



General view of the 80-ton arc furnace from the charging bay, with the control room on the right.

New Arc Furnace has 66 kV. Transformer with On-Load Tap Changing

LORD CHANDOS, chairman of Associated Electrical Industries, Ltd., switched on the power to Britain's largest electric arc furnace at the Stocksbridge works of Samuel Fox & Co., Ltd., on October 3rd. The 20 ft. hearth diameter furnace, which will produce 80 tons of steel at a time, will provide between 1,400 and 1,600 tons of alloy and stainless steels each week for the country's expanding motor vehicle, civil aircraft, steam generation plant and chemical plant industries. It will boost special steel output at the Stocksbridge works from the present 300,000-ton level to nearly 400,000 tons annually.

It is almost exactly three years since Samuel Fox commissioned a 19 ft. hearth diameter arc furnace, which was then the largest in Europe. The new 20 ft. furnace, like its predecessor, was built by Birlec, Ltd., and is a top charged, direct arc unit with three 20 in. diameter electrodes. The stainless steel shell base of the furnace can accommodate an induction stirrer similar to the one fitted on the earlier furnace. Both furnaces are housed in the same melting shop, with control rooms and basement for electricity and other services located centrally between them.

Electric power for the operation of the new furnace is supplied by the Yorkshire Electricity Board at 66,000 volts to an English Electric 20,000 kVA. transformer. The transformer is outstanding in a number of ways: not only is it the largest of its type ever to be manufactured in the United Kingdom, but it is the first to operate directly from a 66,000 volt supply. Also, it employs on-load tap-changing equipment and is the second unit to be installed in this country on which such equipment has been incorporated, the first being the 15,000 kVA. English Electric transformer supplying the 19 ft. hearth diameter furnace.

Direct operation from the local 66,000 volt Y.E.B. supply was made possible by the comparatively recent introduction by English Electric of on-load tap-changing equipment to large arc furnace transformers for steel melting, since no 66,000 volt switchgear is available today capable of the very frequent operation—upwards

of 100,000 times a year—associated with such installations.

By the use of on-load tap-changing equipment on the transformer, the frequency of operation of the main switchgear is reduced to an annual figure of the order of 5,000–6,000, which is within the capabilities of the 66,000 volt air-blast switchgear installed. In addition, on-load tap-changing equipment adds considerably to the ease of operation and makes possible a much finer degree of control of the furnace. Also, by permitting an uninterrupted flow of power, it tends to shorten the melting time, thereby making a further contribution towards reducing the cost per ton of steel produced.

Double Unit Construction

Since this is only the second installation of its kind in this country, in describing the transformer, it appears appropriate to draw a comparison with the original installation. The same basic design has again been used, in that two transformers are mounted together in one common tank, one transformer acting as a voltage regulator and the other as the main step-down transformer to furnace voltage. The voltage regulator is auto-connected, and tappings are brought out from the windings to which the on-load tap-changing equipment is connected. The variable output voltage from this transformer is fed directly into the primary windings of the main step-down transformer, which is entirely without tappings. The secondary windings of the main transformer supply the very heavy current at low voltage to the furnace electrodes. All ends of these windings are brought out and externally connected in delta above the tank.

The principal reasons for the adoption of this "double-unit" construction are that firstly, nowhere within the equipment is a voltage produced which is greater than that of the incoming supply, and secondly, the complete absence of tappings on the transformer directly connected to the furnace considerably increases the mechanical strength of the windings, which is most desirable in view of the very heavy and frequent over-

loads which occur during the melting period. Also, the addition of semi-automatic power factor correction is possible.

This feature was not incorporated on the 15,000 kVA. transformer for the first furnace, but has been provided on the 20,000 kVA. transformer for the new 80 ton furnace. This takes the form of tertiary windings on the main step-down transformer for connection to a 7,000 kVAR. capacitor bank. The voltage available from the tertiary windings has a maximum value of 11,000 volts, and, due to the common primary winding, this voltage varies in direct proportion to that being supplied to the furnace electrodes. Thus, as the voltage to the furnace is reduced, the voltage to the capacitors is simultaneously reduced, and the effective capacitance in circuit is decreased, thereby eliminating the risk of over-correction at low load.

The on-load tap-changing equipment fitted to the 20,000 kVA. transformer is basically similar to that fitted to the 15,000 kVA. transformer, except that it is designed to operate at the higher voltage of 66,000. Reactor-transition is again used, the continuous rating of this type of on-load tap-changing being advantageous on an installation where reliability is of the utmost importance, since no stand-by supply is available. Also, a mechanically stronger winding is possible with this type of tap-changing equipment, since the number of tappings which have to be brought out from the regulator transformer windings is only half the number of the low voltages available. The on-load tap-changing equipment is motor driven, and is controlled remotely by means of a pre-selective voltage control switch in the furnace control room.

Space Problem

One of the major problems which confronted those responsible for the production of this transformer was that, despite the rating of 20,000 kVA. and the incoming supply of 66,000 volts, it had to be accommodated in a substation the same size and a mirror image of that provided for the 15,000 kVA., 11,000 volt transformer supplying the first furnace. Of the three dimensions, the limited height proved the most difficult, but was overcome in several ways, one of which was the use of five limb cores for both the regulating and main transformers. In order not to depart from the leak-proof method, common to all English Electric furnace transformers, of bringing out the L.V. bars through the oil conservator, the whole of the conservator and the tank cover of which it forms an integral part were made of non-magnetic stainless steel. By this means, a further reduction in height was brought about, as it was possible to reduce the distance between the external L.V. delta connections and the transformer superstructure without any risk of local over-heating.

The whole of the equipment is contained in one common tank, and the various tank fittings and refinements, including winding temperature indication and Buchholz protection, associated with modern transformer practice are incorporated. Cooling is by means of duplicate oil-water heat exchangers, either of which is capable of dissipating the full load transformer losses.

In addition to this equipment, English Electric is at present manufacturing two similar transformers of 20,000 kVA. and three of 12,500 kVA. for use with Birlec furnaces to be installed in the United Kingdom.

Annealing Motor Vehicle Forgings

New Electrically Heated Installation for Albion

ALBION MOTORS, LTD., of Scotstoun, Glasgow, are one of the oldest manufacturers of commercial motor vehicles in this country. Many veterans of the first world war will recall the old Albion Army lorries, and the name of the firm has established itself as representative of all that is best in dependable Scottish engineering. Although long established, Albion motors do not lag behind in installing the latest type of equipment for their various manufacturing processes. An example of this may be seen in the electrically heated pusher furnace which has recently been put into commission by G.W.B. Furnaces, Ltd., of Dudley, for annealing various types of forgings, such as main shafts, countershafts, pinion shafts and gear blanks. Heating requirements are that the forgings should be heated up to 900° C. in two hours, soaked at that temperature for one hour, and then subjected to a slow cooling cycle, the temperature of the charge falling to 400-500° C. in five hours.

Owing to the varied nature of the different components and the relatively heavy weight-to-size ratio, it was considered that the best type of mechanism for conveying a charge through the furnace was a hydraulically operated pusher to propel the charge trays along the furnace hearth, in which are set heat-resisting steel skid rails. This method avoids the possibility of any difficulties

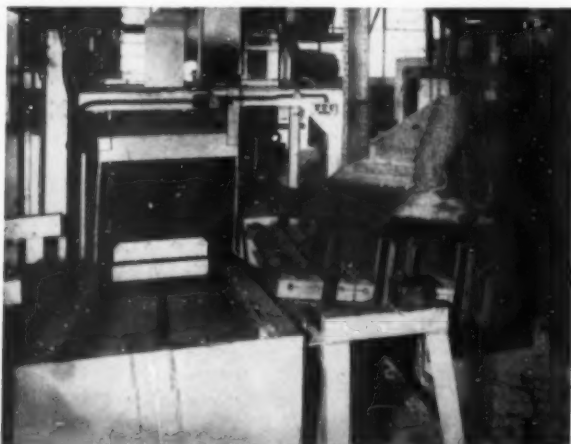
which might arise from rotating parts such as driven or idler rollers subjected to heavy loads at high temperatures. The robust heat resisting steel trays are 2 ft. 6 in. wide × 2 ft. long × 1 ft. high, and carry on an average, a load of 400 lb. In keeping with the present trend towards automatic equipment, the manual work involved in serving this installation is reduced to an absolute minimum. The only labour required is for loading the components into the trays at the charging end of the furnace. By pressing a button situated at the front of the furnace, the following cycle automatically takes place: (1) the entrance door rises; (2) the pusher ram starts to propel the next loaded tray into the furnace; (3) the ram returns; (4) the entrance door lowers; (5) the exit door rises; (6) a hydraulically operated go-getter pulls the last tray out from the end of the furnace on to a cross conveyor. By pushing another button, this cross conveyor moves the discharged tray uphill to the top of an inclined idler roller track running down the length of the furnace. Before the tray returns to the front of the furnace, it is unloaded by a tipper into a waiting stillage. When the empty tray has returned down the inclined track, it is loaded by hand and then moved over automatically in front of the entrance door to commence the cycle once again.

A maximum rating of 145 kW. is arranged in three

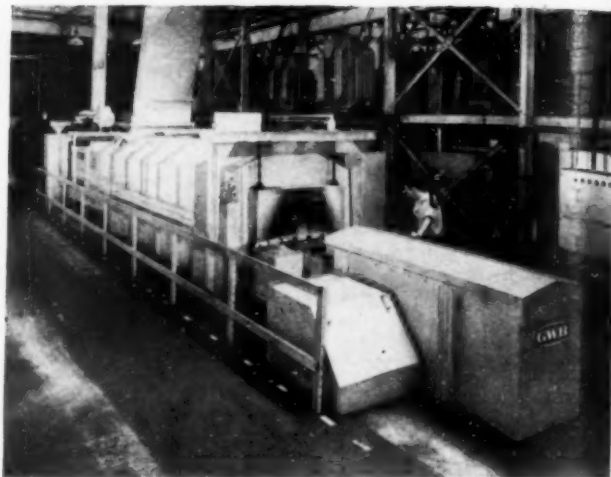


Loaded tray being pushed into the furnace.

independently controlled zones, each of which is governed by a Cambridge potentiometric indicating controller, while a 6-point recording instrument gives a positive check on thermal conditions along the length of the heating and cooling chamber. This last instrument is fitted with excess temperature safety contacts as an additional precaution. The heating chamber is 10 ft. 6 in. long and the cooling chamber, which extends from the end of the heating section, is 18 ft. 3 in. long. In order to prevent too rapid cooling upon leaving the heating chamber, the first section of cooling chamber is fitted with a few heating elements, so that the required gradual cooling curve is obtained. An air cooling fan and a hot air take-off are fitted at the exit point of the furnace.



Charge being transferred from exit end to tilter for unloading of tray.



Overall view of the furnace from the charging end.

An hourly output of 600 lb. of forgings heated to 900° C. is obtained, and the compact nature of the furnace has enabled it to be fitted conveniently into the heat-treatment section without any undue difficulty.

Films Available

PROTOLITE, LTD., announce that they have available for loan to those interested in films for technical education, whether in schools, works or engineering societies, the following 16 mm. colour sound films

Hard Metal (projection time 55 minutes)—Showing in vivid detail some of the manufacturing processes involved in the quantity production of tungsten carbide and a few examples of this important material at work in industry.

Lathe Tools (projection time 25 minutes)—This film seeks to emphasise the importance of correctly handling and maintaining cemented tungsten carbide tipped turning tools.

Milling Cutters (projection time 30 minutes)—By means of "live" shots and models, the cutting action of some single and multi-edge cutting tools is explained simply, followed by demonstrations of the correct application and maintenance of tungsten carbide milling cutters.

Applications for loan should be addressed either to the Company's London office, Central House, Upper Woburn Place, London, W.C.1, or to any of the regional area offices.

Solartron to Sell Direct

FOR some time the Solartron Electronic Group, Ltd., Thames Ditton, Surrey, has been expanding its own sales and distribution organisation in the United Kingdom. Solartron now have complete coverage nationally, and since August 1st, 1957, have operated exclusively through their own organisation. All enquiries should be sent direct to Solartron at Thames Ditton, or telephoned to Emberbrook 5522.

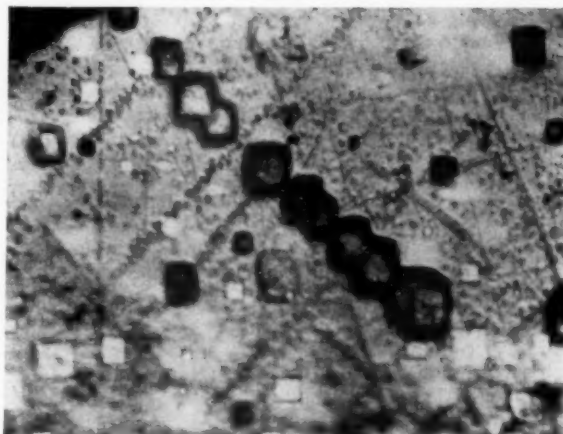
Square Bubbles in Irradiated Lithium Fluoride Crystals

IRRADIATION of materials sometimes produces astonishing results. For instance, the use of radioactive isotopes is known to change the molecular structure of plastics, rubber and other organic materials. A recent discovery of an unusual character was made during radiation experiments at the Knolls Atomic Power Laboratory at Schenectady, New York, which is operated by the General Electric Co. of America for the U.S. Atomic Energy Commission. A series of radiation experiments using neutrons was being carried out, and in one of these experiments square bubbles, believed to be the first such phenomena ever observed in nature, were discovered by Mr. Peter Senio, a metallurgist in the laboratory. Brilliantly coloured microscopic bubbles in square and rectangular forms appeared in lithium fluoride crystals after they had been exposed to neutron radiation and then heated to a temperature in excess of 600° C.

As far as is known, such bubble enclosures of square or rectangular shape have never before been seen in any other material. No bubble enclosures at all were found in lithium fluoride that had not first been irradiated with neutrons. Normal lithium fluoride is a clear, glass-like material, which undergoes physical changes within a few days, rather than in months, as is the case with many metals when irradiated.

During these experiments, the lithium fluoride bubbles appeared first in bright colours, showing that the bubble enclosures have a third dimension, although they are extremely thin, measuring only about one-hundred-thousandth of an inch. As the bubble enclosures become thicker, they appear white.

It is believed that formation of helium and tritium gases in the irradiated lithium fluoride is responsible for the bubbles. So far, however, no explanation can be



Square bubbles in irradiated and heated lithium fluoride crystal. ($\times 250$)

given why square and rectangular bubbles appear rather than conventional spherical ones. At first glance, the discovery of box-like bubble enclosures in a material have no practical value, but it is possible that they may lead to important scientific discoveries regarding the fundamental atomic structure of matter.

Technique of Production

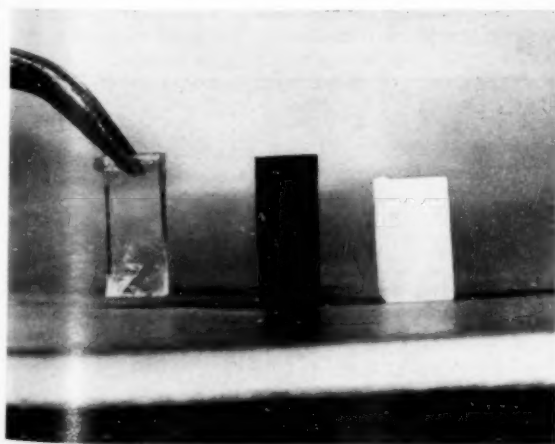
The technique for the production of these square bubble enclosures is as follows. First, small pieces of clear lithium fluoride are irradiated with neutrons in a reactor. Once exposed to irradiation for a time, they turn black. Next, these irradiated crystals are heated in a laboratory furnace, and when they reach about 450° C., they turn clear, or almost clear, again.

When heated to about 700° C. for several hours, they look frosty to the naked eye. At this stage they are taken from the furnace and allowed to cool. Studied under a microscope, the crystals reveal colour squares formed inside—usually along natural faults in the crystal structure. Overall appearance of groups of the bright bubbles is somewhat similar to squares used in stain glass windows arranged in cubist design. If the temperature of the furnace is boosted above 700° C., the bubbles inside the crystals turn white and their corners begin to round.

As the melting point of lithium fluoride (842° C.) is approached, the bubbles grow and combine to form new shapes that resemble sausages, doughnuts, boomerangs and many familiar objects. The ultimate form of the bubbles, when heated near the melting point of the material, appears to be spherical.

Acknowledgment

Acknowledgment is due for illustrations to The International General Electric Company, 150 East, 42nd Street, New York, U.S.A.



The crystal on the left is normal lithium fluoride; irradiation produces the black appearance shown by the centre crystal, and subsequent heating in the neighbourhood of 700° C. results in the "frosted" appearance shown on the right.

New Advance in Rolling Mill Bearings

United Coke & Chemicals' New Product

THE use of a new reinforced synthetic resin is now making it possible in certain cases to double the life of bearings in steel rolling mills, and in almost all cases to give a substantially improved performance. After four years of applied research and trials, United Coke and Chemicals Co., Ltd., a subsidiary of the United Steel Cos., Ltd., have begun full-scale production of their new Orkot bearings at the Orgreave works, near Rotherham.

Rolling mill bearings have been made of various alloys, white metal and bronze being the most widely used, until the comparatively recent introduction of bearings made of fabric or fibre bonded by synthetic resins presented engineers with a new material. The principal advantages of fabric over metal bearings lie in their lower friction coefficients, higher strength to weight ratios, and greater wear resistance. Hence, they last longer, lead to considerable saving in power and, by enabling mills to operate for longer periods between bearing changes and adjustment, make higher outputs possible. Orkot bearings are the latest development in this field.

After initial laboratory tests had shown that Orkot possessed excellent bearing characteristics, an extensive series of full-scale trials was carried out in a number of rolling mills at the steelmaking branches of United Steel, with outstanding results. Over a period of months, big power savings were recorded on mills fitted

with these bearings, while at the same time output increased—in one case by as much as 20%. Moreover, because of the excellent wearing properties of the bearings, the number of sections rolled outside size limits was substantially reduced.

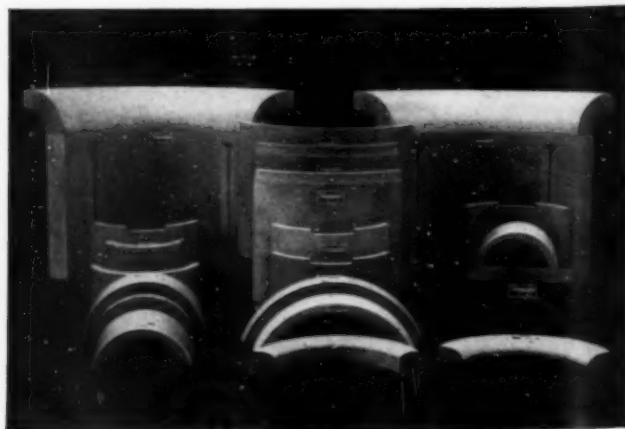
The lives of individual bearings in the same position in a mill always vary due to external factors and, to be significant, comparisons must be carried out on a large scale. United Steel's tests involved several hundreds of bearings over a three-year period, and the results obtained can fairly be regarded as representative.

The following table shows results obtained on one of the mills concerned:—

	Conventional Bearings	Orkot Bearings
Average tonnage rolled per set of bearings	700 tons	3,500 tons
Bearing cost per ton	1s. 4d.	5½d.
Annual bearing renewal cost . .	£1,034	£410
Electrical power consumption per ton	61 units	35 units

As the time taken for new Orkot bearings to "bed in" is shorter than for bearings made of other materials, the risk of damage from overheating in the first few hours of use is sensibly diminished. The bearings are designed primarily for use with water lubrication. The success of this depends on the maintenance of a continuous water film between the bearing and the roll neck, and the excellent "wettability" of Orkot helps to preserve this water film effectively.

In anticipation of a big demand from the metal rolling industries, United Coke and Chemicals Company have built and equipped a new plant for the manufacture of Orkot bearings, and are now in a position to meet the needs of prospective users.



Left—One stand of a rod mill showing position of Orkot bearings. In this installation the bearing is a complete structure, consisting of two liners and a collar; Right—Selection of Orkot liners and thrust collars for various types of rolling mills.

NEWS AND ANNOUNCEMENTS

Metal Physics Symposium

A SYMPOSIUM on "Vacancies and Other Point Defects in Metals and Alloys" is being arranged by the Metal Physics Committee of the Institute of Metals to be held at Harwell on Monday and Tuesday, December 9th and 10th.

On the first day there will be a visit in the afternoon to certain aspects of research work at the Atomic Energy Research Establishment, together with a brief visit to the reactor DIDO, while in the evening there will be an introductory lecture, for the benefit of non-specialists, by Professor R. W. K. Honeycombe of the University of Sheffield. The second day will be devoted to the Symposium itself, and the discussion will be based on a series of six papers, which will be available, in advance, only to those who register for the meeting.

The Symposium will be open to non-members as well as to members of the Institute. Owing to restrictions on the numbers that can be accepted, attendance, however, will be by registration only. A basic registration fee of £1 5s. 0d. will be charged to cover the advance copies of papers, and lunch, coffee and tea and transport to and from Oxford or Didcot will be provided at additional cost, for those who desire them.

Details of the meeting, with Registration Form, may be obtained from the Secretary, The Institute of Metals, 17 Belgrave Square, London, S.W.1.

Stainless Steels for Petroleum Industry

MR. J. WILLIAMS, Sales Manager, and Mr. F. A. Kirk, Metallurgist of Samuel Osborn and Co., Ltd., Sheffield, attended the Study Days of the Federation of European Petroleum Equipment Manufacturers at Stuttgart from October 9th to 12th, when they delivered a paper on "Stainless Steels for the Petroleum Industry," giving the general relationship between British and American qualities. The petroleum industry demands an extremely wide variety of materials of corrosion and heat resisting properties, and this is probably the first time that comprehensive information has been collated on the relative stainless steels for this industry. The paper was one of a number presented by members of leading companies in the United Kingdom, France, Germany, Italy, Holland and Belgium.

Import Duty on Iron and Steel Sheet

UNDER the Import Duties (Exemptions) (No. 6) Order, 1957, the import duties on a wide range of iron and steel products are suspended until March 18th, 1958, and under the No. 10 Order, 1957, the suspension of duty on almost all plates is prolonged until September 18th, 1958. After consultation with the Iron and Steel Board about the supply position, Her Majesty's Government have decided that the suspension of duty on most types of cold-reduced sheet of a value of less than £90 per ton should also be prolonged until September 18th, 1958. A new Order, the Import Duties (Exemptions) (No. 12) Order, 1957 (S.I. No. 1625) has been made, and will come

into operation on March 19th, 1958. Copies of the Order may be obtained from H.M. Stationery Office or from any bookseller, price 3d. (by post 5d.). The question of further suspension of duty on other iron and steel products after March 18th, 1958 is being examined; an announcement in respect of the duties on these other products will be made in due course.

Nickel Exhibition in Newcastle

AN exhibition to bring industry the latest information about the uses and developments of nickel, nickel alloys and related materials, is to be held by The Mond Nickel Co., Ltd., at the Royal Station Hotel, Newcastle-on-Tyne, from November 5th to 8th. It will be open from 10 a.m. to 7 p.m. each day. Numerous displays and working demonstrations are planned, to show corrosion resistance, surface protection, high magnetic permeability, weldability, controlled expansion, and mechanical properties at temperatures between 900° C. and sub-zero. Part of the exhibition will be devoted to spheroidal graphite cast iron, and will feature specimens and mechanical strength tests.

Disposal of Stockpile Lead

ON January 23rd, 1957, the Board of Trade announced that they had decided to sell about 30,000 tons of lead for delivery over a period ending in November 1957. In continuation of the policy set out in the 1956 Defence White Paper (Cmd. 9691, paragraph 125) of running down strategic holdings of industrial raw materials, the Board now announce that they intend to dispose of the whole of their remaining stocks of lead, amounting to about 20,000 tons. No detailed plans as to the method and rate of disposal can be announced until discussions have been held with trade representatives, but the monthly rate of disposals is in any event unlikely to exceed the present rate of some 3,000 tons a month. No lead will be offered for delivery before December 1957.

Low-Temperature Deformation of Metals

A LECTURE on "The Low-Temperature Deformation of Metals" is to be given by Dr. T. H. Blewitt, of the Oak Ridge National Laboratory, Oak Ridge, Tenn., on Thursday, November 14th, 1957. The lecture, which is being arranged by the Metal Physics Committee of the Institute of Metals, will take place at the Institute's Headquarters, 17 Belgrave Square, London, S.W.1, at 6-30 p.m. The meeting is open to visitors without ticket.

Conference Report

WE understand that orders are now being taken for the Report of the Conference on Low-Alloy Steels for Welded Pressure Vessels, organised by The West of Scotland Iron and Steel Institute and held in Glasgow in October, 1956. The report consists of 210 pages, containing the full text of the papers read and the discussion thereon, and forms part of Vol. 64 of *The Journal of the West*

of Scotland Iron and Steel Institute. The price is 42s., and orders should be sent to the Institute at 39 Elmbank Crescent, Glasgow, C.2.

Non-Destructive Testing Conference

THE British National Committee for Non-Destructive Testing will be represented by a delegation of three members to the Second International Conference on Non-Destructive Testing to be held in Chicago during November. This delegation will be led by Dr. L. Mullins, who represents the Society of Non-Destructive Examination, and who is Manager of the Technical Advisory Department of Kodak, Ltd. The other members of the delegation are Mr. C. C. Bates, who represents the Institution of Production Engineers, and who is Technical Director of Welding Supervision, Ltd., and Dr. J. Thewlis, Assistant Head of the Metallurgy Division of the Atomic Energy Research Establishment at Harwell.

Microscope Exhibition

WITH the title of "The Microscope in Industry and Research," W. Watson and Sons, Ltd., are holding an exhibition at the Birmingham Exchange and Engineering Centre, Stephenson Place, Birmingham 2, from November 4th to November 8th, 1957.

B.I.S.F. Office Bearers

THE Council of the British Iron and Steel Federation has appointed Mr. Lewis Chapman, C.B.E. (Chairman, William Jessop and Sons, Ltd.) President-Elect of the Federation in succession to the late Mr. Gerald Steel, C.B.E. Sir Andrew McCance, F.R.S. (Chairman and Managing Director, Colvilles, Ltd.) has been invited to continue in office as President of the Federation for 1958.

Industrial Efficiency Exhibition

THE first of its kind to be held in the North, The Industrial Efficiency and Productivity Exhibition will be held at the City Hall, Deansgate, Manchester, from November 5th to 16th, 1957. The exhibition is sponsored by the Institute of Works Managers who have arranged a conference during the exhibition period.

"Forgemasters in Steel"

THE new English Steel Corporation colour film—"Forgemasters in Steel"—was given its main preview on October 9th, at The Savoy Hotel, London. This film is also to be introduced shortly to other centres, beginning with Manchester on December 2nd and followed by Newcastle, Birmingham and Glasgow. Copies of the film will be available for distribution from January 1st, 1958, to Technical Societies, Schools, Colleges and other organisations who feel the film will be of instructional value to their members. The film was also to be shown at Harrogate in October during the Festival of Films in the Service of Industry, having been selected for final competition in the Sales Promotion category.

"Forgemasters in Steel," which runs for 48 minutes, traces the role played by E.S.C. in the history of steel forging and then deals with present day processes. It contains excellent shots of steel melting and teeming, the casting of large ingots and their subsequent forging and

testing. Except for the commentary, which is spoken by Mr. Frank Phillips, the film is an entirely E.S.C. production, and was produced by the Company's Film Committee under the present Chairmanship of Dr. C. J. Dadswell. The photography was carried out by the E.S.C. Film Unit.

Sponge Iron Powder

THE Board of Trade announced on March 17th, 1956, that they were considering an application for a protective duty on a certain grade of sponge iron powder. The Board now announce that, after consultation with the applicants, the application has been withdrawn.

Personal News

HADFIELDS, LTD., announce that DR. J. R. RAIT, Research Controller, has left, with their grateful thanks for the good work he has done for them and their best wishes for his future success, to take up a new appointment as Joint Managing Director of Briton Ferry Steel Co., a subsidiary of Duport, Ltd. Mr. T. H. ARNOLD, M.B.E., has been appointed Research Controller and Local Director of Hadfields, Ltd., and has also been appointed to the Board of Hadfields Steels, Ltd., and Hadfields Forgings, Ltd. DR. L. G. FINCH has been appointed Deputy Research Controller with effect from October 1st, 1957. Mr. D. R. EASTWOOD, Deputy Chief Engineer, has been appointed a Local Director of Hadfields, Ltd., and a Director of Hadfields Foundry & Engineering Co., Ltd. Mr. S. LEETCH, M.C., Works Controller, who has retired, takes with him to the North-East coast the best wishes of employees and management.

SAMUEL FOX & Co., LTD., announce that MR. D. N. RILEY has been appointed Manager of their Rotherfield Works and MR. E. E. BEARD Manager of the Laminated and Coil Spring Departments. MR. A. ASPINALL is to be transferred from the Rotherfield Works to become Assistant Manager of the Laminated and Coil Spring Departments at Stocksbridge. MR. E. HAMPSHIRE, Technical Superintendent, Spring Manufacture, is being given certain additional technical and liaison duties in connection with the Umbrella Department.

MR. R. G. WILKINSON has relinquished his appointment as Development Manager of Magnesium Elektron, Ltd. He is succeeded by Mr. K. G. D. BAILEY.

MR. E. L. BURTON has been appointed Secretary of Tube Investments, Ltd., in succession to MR. I. N. TURNER, who has taken up other duties in the group. Mr. Burton retains his responsibilities as Chief Accountant.

MR. N. HARVEY, Chief Metallurgist, has been appointed Development Manager of the Aston Chain & Hook Co., Ltd. He will be in charge of all research, development and laboratory services, and his responsibilities will also embrace work and method study and labour incentive schemes.

MR. A. J. PEECH has been appointed General Managing Director of The United Steel Cos., Ltd., in succession to the late MR. G. STEEL. Mr. Peech was formerly Deputy General Managing Director.

RECENT DEVELOPMENTS

MATERIALS : PROCESSES : EQUIPMENT

Protective Gloves with P.V.C. Coating

A NEW range of flame-proof protective gloves has been introduced by the protective equipment division of Martindale Electric Co., Ltd. The new gloves are coated with P.V.C. (polyvinyl chloride) which renders them resistant to heat, chemicals, acids, greases and oils. The tough P.V.C. coating is bonded on to an interlock fabric lining, and this internal support, whilst making the gloves more durable, in no way reduces their flexibility.

Martindale claim to have eliminated what has previously been one of the main disadvantages with this type of glove—the fact that seams have often run across the parts of the surface which receive most wear. The number of seams in the P.V.C. gloves has been reduced to a minimum, and they are positioned away from wearing surfaces. To give even greater freedom of movement, the gloves are moulded with the thumb and fingers in the position of a relaxed hand. There is no seam at the junction of thumb and index finger so that there is virtually no drag against the thumb when the wearer's hand is fully opened.

The gloves can easily be cleaned and sterilised by washing in boiling water using a mild detergent or soap; they can also be turned inside out and the linings washed—an economy as well as a health measure as it ensures a longer wearing life. They are available in rough or smooth finishes for medium, light and heavy work: with open or close fitting wrists; and also with ribbed safety palms.

Martindale Electric Co., Ltd., Westmorland Road, London N.W.9.

Metallographic Potentiostat

A TECHNIQUE originally developed for the study of certain corrosion phenomena, and in particular the passivity of stainless steels, has possibilities in the metallographic field. It involves maintaining the potential of a specimen immersed in a solution at any desired value relative to a standard electrode by the use of a potentiostat, and Shandon Scientific Co., Ltd., have recently introduced an instrument for the purpose. This device makes use of a third electrode placed in the electrolyte and connected to a circuit drawing negligible current. This electrode monitors the potential between the electrolyte and the specimen, and the monitored value is used to control the supply so as to maintain the required constant potential.

For metallographic studies, the potentiostat has several immediate uses which can be exploited to advantage, such as controlled etching; the detection of susceptibility to intercrystalline corrosion; the study of phase diagrams; and the detection of unwanted inclusions in metals.

If an alloy contains two or more phases, each will behave more or less independently of the others, and if the potential is so chosen that one of the phases corrodes



very much more rapidly than the others, differential etching of that phase will result. By etching at various potentials, quite different portions of the alloy can be selectively attacked. The fact that, with the potentiostat, the potential can be measured by the valve voltmeter and the polarising current by the ammeter, during etching, means that it should be possible to say whether a phase has exactly the same etching characteristics as it had in some other alloy previously studied, which may be useful if it is desired to know whether it has the same composition. Additional information may be obtained by measuring the currents supplied by the potentiostat, and an interesting example is the detection at grain boundaries of the small traces of material which cause susceptibility to intercrystalline corrosion. Coupled with analytical work, the potentiostat technique can be used to analyse the material at the grain boundaries of susceptible steels, or a phase of a duplex alloy.

The Shandon instrument is contained in 12 x 7 x 8 in. cabinet, complete with internal power supply, output terminals, etc. The applied potential is variable from + 2V. to - 2V. and the output current from + 50 mA. to - 50 mA., the values being shown by two meters on the face of the instrument. A socket is provided so that the applied voltage may be obtained from an external source. This is useful where the potential is required to change in a known manner with respect to time, when a motor driven potentiometer may be used.

Shandon Scientific Co., Ltd., 6 Cromwell Place, London, S.W.7.

Motor Generator Welding Set

QUASI-ARC, LTD, have added a new motor-generator to their range of manual welding equipment. Known as the MGB 400, it is of light yet robust construction, and its small size permits of easy manoeuvrability. It is particularly suitable for depositing electrodes frequently used in positional pipe welding, most of which fall in



the AWS/ASTM classification E.6010 or the B.S. classification E.110. The unit gives stable arc conditions when used with the new Quasi-Arc Celtian electrodes for pipe welding.

The principal details of the MGB 400 are as follows:—

Maximum current	400 amp.
Maximum continuous current	300 amp.
Continuous test current	210 amp.
Minimum open circuit voltage	55
Maximum open circuit voltage	95
Speed	1,500 r.p.m.
Weight	
Without undergear	9½ cwt.
With undergear	10 cwt.
Overall dimensions	
Without undergear	3 ft. 4½ in. × 1 ft. 7 in. × 2 ft. 11 in. high.
With undergear	3 ft. 6½ in. × 2 ft. 1½ in. × 3 ft. 6 in. high.

A novel form of brushgear is used, which allows very rapid adjustment to spring tension and brush withdrawal. The large brush area ensures sparkless commutation at all loads. The rotor of the motor and the generator armature are mounted on the same shaft, which is supported at each end by a large ball race fitted with a grease nipple. The end-shields are of light, robust fibreglass, and are easily removable to allow access to the generator brushgear and motor.

Starting is simplified by the use of an automatic star delta starter. When the operator pushes a button, the remainder of the starting operation takes place automatically. A novel system of current and open circuit voltage regulation is also used, which ensures that the current selector switch cannot be left at mid-point between any two of its correct positions. The system also enables the operator to adjust the volt-amp characteristic of the equipment, so that welding conditions can be varied to suit exactly the work in hand. The set is provided with facilities for single-point lifting, and among the optional extras which can be supplied are an ammeter and voltmeter and a steerable four-wheeled undergear.

In view of its suitability for depositing pipe welding electrodes, the ease of servicing and maintenance, and

its relatively small size, this set should prove of value for a wide variety of applications both in the welding shop and for site work.

Quasi-Arc, Ltd., Bilston, Staffs.

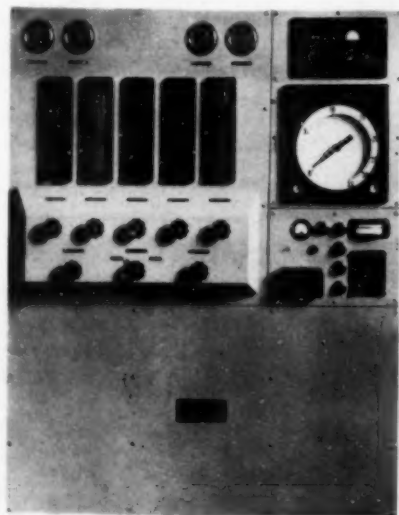
Chemical Polishing Solutions for Copper Alloys

ALBRIGHT & WILSON (MFG.), LTD., have completed development of two additions to their range of Phosbrite chemical polishing solutions. These solutions, available initially on an experimental basis, are Phosbrite 183, for treating basis and cartridge brass, and Phosbrite 184, for gilding metals. The solutions produce bright, highly reflective surfaces on the metalwork in 1 to 3 minutes. Their development represents an important advance in quality of finish, ease and accuracy of control and economy in this type of process. No desmudging is required, the polished metal being rinsed in cold water and then dried. Surfaces may subsequently be nickel-chromium plated or lacquered, or left in their chemically polished state. The polishing tanks can be made of stainless steel, P.V.C.-lined mild steel, chemical stone-ware or glass, and the solutions are operated at optimum temperatures of 65° C. and 60° C., respectively. Fume extraction equipment is essential and may be made of P.V.C.

The Metal Finishing Department, Albright & Wilson, (Mfg.), Ltd., 1 Knightsbridge Green, London, S.W.1.

The G.N.L. Nitronal Generator

THE Baker Platinum Division of Engelhard Industries, Ltd., have produced a new and improved model of their Nitronal Generator—an apparatus which produces furnace and blanketing atmospheres, consisting of nitrogen with a controllable hydrogen content, using ammonia as fuel. The new model, known as the GNL Nitronal Generator, is made in two sizes, to produce 500 and 1,500 cu ft./hr. of gas, and, unlike the earlier models, which required an ammonia vapour supply,



the new GNL Generator has a built-in vaporiser and is fed with liquid ammonia direct from the cylinders. The refrigerant properties of the ammonia are used to cool the gas down to a dew-point of 40° F.

The gas is produced by cracking the ammonia over a precious metal catalyst into its constituents nitrogen and hydrogen, and the same catalyst is used to burn the bulk of the hydrogen with atmospheric oxygen to produce a gas containing from 0.5–25% hydrogen. The principle advantages obtained by using the special Baker catalyst in this way are that the reaction is exothermic and no external heat source is required, and, secondly, that in utilising nitrogen from the atmosphere as well as from the ammonia the gas is produced very economically.

In the new GNL model, a second stage catalyst chamber is used when the hydrogen concentration required is less than 15%, and this further change in design considerably prolongs the life of the catalyst. It also ensures that the oxygen content of the gas is less than one part per million. The hydrogen content of the gas is controlled automatically within 0.25% of the desired concentration, and the generator only requires the attention of an operator for starting, which takes about 20 minutes. There are no pumps or other moving parts, and servicing and maintenance are therefore reduced to a minimum.

*Baker Platinum Division, Engelhard Industries, Ltd.,
52 High Holborn, London, W.C.1.*

New Aluminium Sheet Finish

A NEW type of Noral "Grey" aluminium sheeting is now available from Northern Aluminium Co., Ltd., in response to demand from coachbuilders for a sheeting with a surface finish that has improved adhesion for paints. Tests of the normal tensile loads which the paint-to-metal joint will withstand have shown that Noral "Grey" sheet is about two-and-a-half times as effective as ordinary bright aluminium sheeting. It must be emphasised, however, that this keying, produced by mechanical means, does not dispense with any of the usual precautions that should be taken when preparing an aluminium surface for painting—the results, however, will be much better. This new finish is at the moment available only in a limited range of alloys and tempers; it is available, however for Noral 2S½H and 3S½H (conforming to B.S.1470 SIC and NS3, respectively)—two of the alloys most commonly used for coach and caravan panelling. This sheeting is suitable not only for coach, caravan and motor body building, but also for any other applications where aluminium sheeting is required in a painted condition.

Northern Aluminium Co., Ltd., Banbury, Oxfordshire.

Portable Current Density Indicator

THE latest addition to the range of English Electric instruments is a portable current density indicator, which is an invaluable aid to production in the electroplating industry. By giving a direct reading in amp./sq. ft., this indicator enables the current density in the electrolyte at any point of any number of loaded electroplating vats to be checked rapidly, and their operating



currents adjusted for maximum plating efficiency and consistency of quality.

The apparatus consists of a robust moving-coil ammeter connected in series with a plate electrode of known surface area. The electrode is immersed in the electrolyte between the component to be plated and the anode. When contact is made to the work bar through the forked spike on the ammeter case, a direct indication of current density in the vat at that point is given on the ammeter dial.

Two electrodes are supplied, one of stainless steel for use in stannate tin, zinc and cadmium vats, where current density does not exceed 50 amp./sq. ft., and a second patented glass-backed electrode for use in chromium and bright nickel vats where current density is up to 250 amp./sq. ft. Selection of the correct electrode enables readings with an accuracy of $\pm 5\%$ to be readily obtained.

*The English Electric Co., Ltd., Instruments Sales and
Contracts Department, Stafford.*

Plastic-Coated Steel

It is expected that Stelvetite, a plastic-coated steel sheet, recently introduced by John Summers & Sons, Ltd., will find widespread application in industry. It can be worked and treated as ordinary steel sheet, while its outer surface retains all the characteristics of P.V.C. plastic, produced in a varied range of colours and embossed patterns. The outer plastic surface is a permanent, complete finish in itself, being extremely easy to clean and maintain.

This is steel with a "new look" and a "new touch," offering a host of possibilities in the manufacture of furniture, motor cars, building materials, electrical goods, and many types of domestic and industrial items, combining the strength and durability of steel with the finish and texture of plastic. The use of Stelvetite eliminates the need for surface finishing treatments, and from the cost aspect, it is an attractive proposition, being cheaper than stainless steel.

Developed by John Summers & Sons, Ltd., in conjunction with B.X. Plastics, Ltd., Stelvetite is strip mill cold reduced steel with a specially formulated Velbex P.V.C. coating. The reverse side of the sheet can be

either a Bonderized steel or electro-zinc-coated surface. It can be bent, formed, seamed, deep drawn and joined without damaging the coating; it is warm and pleasant to the touch, has excellent electrical insulating properties, and is highly resistant to acids, alkalis, greases, detergents, weather, humidity, and abrasion. It does not support combustion, and is stable at higher temperatures than P.V.C. alone.

Stelvetite is available in steel gauges from 26 s.w.g. (0.0196 in.) to 16 s.w.g. (0.0625 in.), and in sheet lengths and widths of up to 144 in. and 48 in. respectively; the P.V.C. coating is 0.014 in. thick. It can be supplied in almost any colour, in any of the Stelvetite range of embossings.

Dept. MRD/16, John Summers & Sons, Ltd., Shotton, Chester.

Pyroclean No. 8

DEVELOPED to overcome the main disadvantages of emulsion cleaners and alkali cleaners of the orthodox type, Pyroclean No. 8 is composed of extremely mild activated alkali material, and contains no caustic or other harsh ingredient. It is actually milder than many normal domestic detergents. In addition to its mild character, Pyroclean No. 8 also contains no paraffin constituent, and thus presents no problems in the disposal of effluents.

Pyroclean No. 8 can be used in any kind of spray washing machine, and cleans ferrous and non-ferrous parts with equal facility. Its marked economies derive from the extremely low concentration at which the

cleaner is used (0.1-0.2%) and its low operating temperature (130-160° F.). It can be used in all applications where alkali or emulsion cleaners are ordinarily operated, and for many purposes it can replace solvent vapour degreasing. No subsequent rinsing in water is necessary, and the material imparts to the cleaned work a degree of resistance to rust and corrosion during periods of heavy storage.

The Pyrene Co., Ltd., Metal Finishing Division, Great West Road, Brentford, Middlesex.

High Strength Torque Bolts

A NEW form of connection for structural steelwork which replaces the conventional riveted joint and increases the speed of erection is being shown by United Steel Structural Co., Ltd., at the Building Exhibition at Olympia.

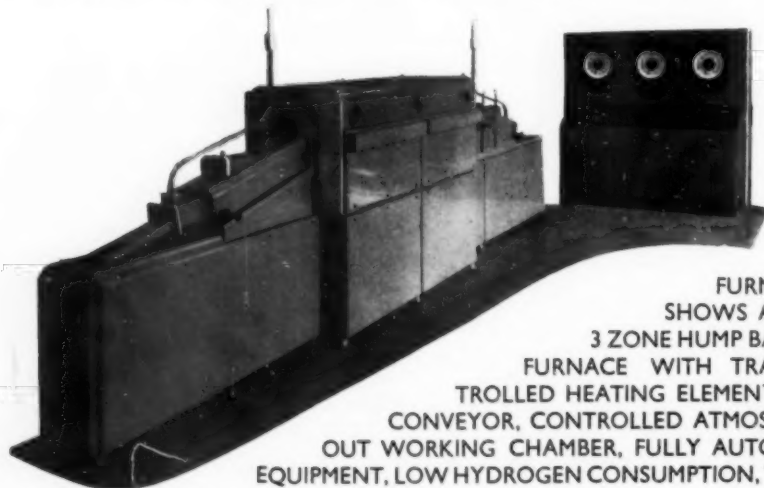
In the usual riveted structure, the strength of a joint is dependent upon the shear or bearing value of the rivets. The new system, which employs high strength torque bolts, establishes considerable tension in the individual bolts, so that the strength of a joint is developed by friction at the interfaces of the connected sections. Each bolt is torqued up to a predetermined value, using hardened steel washers under the head of the bolt and under the nut. In addition to greater strength, connections can be made with the new torque bolts much more quickly than with site rivets or fitted bolts, while dispensing with the need for service bolting.

United Steel Structural Co., Ltd., 17 Westbourne Road, Sheffield, 10.

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CURRENT LITERATURE

Book Notices

THE SOLIDIFICATION OF CASTINGS

By R. W. Ruddle, 392 pp., including two appendices, 8½ × 5½ in., with 176 illustrations. May, 1957. The Institute of Metals, 4, Grosvenor Gardens, London, S.W.1. 42s. net.

DURING the last two decades considerable attention has been directed to the application of scientific methods in the design and production of castings, which has resulted in the carrying out of work on many different lines of investigation. For centuries the casting of metals was regarded as an art rather than a science, but the effect of research on the problems associated with the production of sound castings is gradually placing it on a scientific basis. There are many factors connected with this field of exploration, some of which involve work on the underlying principles, while others are concerned with more practical aspects. It is the latter phase, the way in which metals solidify, on which this book concentrates.

The first edition of this monograph was published in 1950, and since that time considerable work on the solidification of castings has been published and discussed in technical literature. This has necessitated a complete revision of the original text and the inclusion of much new matter. The present volume, which is very much longer than the first edition, surveys critically and summarises the researches that have been carried out into solidification, and presents the results to the reader in a more readily assimilated form.

For many years it was generally accepted that solidification of castings proceeded from the surfaces in contact with the mould, towards the centre of the sectional thickness, and this view is still held, although few now believe that the solid and liquid portions are separated by a sharp line of demarcation; probably that belief arose from the production of slush castings. When molten metal has been cast into a mould, a skin of solid metal is formed almost instantaneously, and, apart from the runner and possibly a riser, it completely envelopes fluid metal which progressively freezes towards the centre of the sectional thickness. What is not so readily appreciated is the fact that, particularly with alloys, the freezing is selective, and that the composition of the liquid along the solid-liquid interface is constantly changing. Detailed studies during recent years on the solidification of metals and alloys have revealed marked differences in the form in which solidification proceeds, and have shown the great influence many factors have on the mechanism involved in freezing.

It is with studies of factors that influence the mechanism of solidification that this book is concerned. Apart from the first chapter, which gives a short account of the principal experimental methods used in studying the solidification of castings, the author has concentrated on the results of these studies, and discusses them critically with a view to assisting further work on the subject and the practical application of the theories advanced towards the production of sounder castings. The qualitative aspects of the mechanism of freezing are discussed and a chapter is devoted exclusively to the mathematics of the flow of heat in solidifying castings and in moulds. Experimental work on the flow of heat in sand and ingot

moulds is reviewed; this is of fundamental importance, since solidification rates in castings are governed almost entirely by the rate at which the mould can remove heat. Freezing rates in sand and chill castings are discussed, and the effects on freezing rates of the shape and size of the casting, of the thermal properties of the metal, and of various other factors are described. The rates of heat flow and solidification obtaining in the manufacture of ingots by continuous casting processes are also considered, and more practical matters discussed include the relation between the conditions of solidification of a casting and its soundness, the factors determining the type of porosity in poorly fed castings, the mechanism of feeding, the efficiency and effective range of feeders, the value of chilling, and the way in which basic information on these subjects may be employed to improve the soundness of castings.

There are two Appendices: the first lists and discusses information available on the high-temperature thermal properties of metals and mould materials; the second consists of two of the mathematical functions used in computing heat-flow rates in castings and moulds. In addition the book includes a comprehensive bibliography on the subject. Although primarily intended for research workers and advanced foundry technologists, this book is of considerable value to the practical foundryman because the soundness of castings depends so much on the manner in which the metal solidifies.

Trade Publications

WE have received from Griffin & George, Ltd., the laboratory furnishers and manufacturers of scientific apparatus, five new pieces of printed literature, all available on request from the Company's Head Office at Alpertown, Wembley, Middlesex, or their Branches in Birmingham, Manchester, Glasgow and Edinburgh. They are, Physical Laboratory Apparatus Price List P.2026 (4 to 116 pp.); Laboratory Furniture Catalogue P.2029 (4 to 40 pp.); Price List of Soil Mechanics Testing Apparatus P.2033 (4 to 28 pp.); Griffin Raybox Leaflet P.2022 (8vo 4 pp.); and Nivoc Force-on-a-Conductor Balance Leaflet P.2024 (8vo 6 pp.) The two last named deal with new products.

THE range of isotope transporting containers marketed by Savage & Parsons, Ltd., of Watford, Herts., is described and illustrated for the first time in a new leaflet. The lead containers are specially made to the design and specifications of the United Kingdom Atomic Energy Authority, and are used to carry isotope cans and other similar vessels in common laboratory use, enabling radioactive and toxic materials to be transported safely outside protected areas. Also illustrated is a tong assembly and a range of handling tools for charging and emptying the containers.

To anyone thinking of seamless steel tubes as being circular in cross section, "Tubular Sections"—an 84-page catalogue published by Accles & Pollock, Ltd.—will come as something of an eye-opener. There must be hundreds of different tube shapes detailed, and many of them can be produced in a wide range of sizes. In

many instances, the use of tubing affords considerable economy in both material and production time, and anyone who is interested in the matter will find much useful information in this brochure.

WE have received from the English Electric Co., Ltd., three new publications on recently introduced welding equipment. The first, a 12-page booklet, deals with the three-phase, multi-operator, A.C. welding plant, reference being made to transformers, rectifiers and distribution equipment. The other two leaflets deal, respectively, with a new portable rectifier welding equipment and a new range of welding transformers.

REFERENCE was made in our news columns some months ago to the agreement between Wild-Barfield Electric Furnaces, Ltd., and the National Research Corporation of Massachusetts, U.S.A., concerning vacuum furnaces. Wild-Barfield have recently issued a leaflet dealing with a resistance heated vacuum furnace, suitable for operation at temperatures up to 2,000° C., made to the designs of National Research Corporation. Over 70 of these laboratory vacuum furnaces have been supplied.

THE October issue of *Platinum Metals Review*, published by Johnson, Matthey and Co., Ltd., contains a number of articles of metallurgical interest dealing with such subjects as liquid steel temperature measurement, thermocouples, creep testing of platinum alloys, alloys of platinum metals with boron, phosphorus and silicon, and the extraction and purification of plutonium metal.

FOR some years now the aluminium alloy, Hiduminium RR58, has been used for high temperature applications, and as a result of the reliability and good mechanical properties of this alloy at elevated temperatures, interest has been expressed in its use for the skinning of supersonic aircraft and guided weapons. For this purpose, High Duty Alloys, Ltd., have produced RR58 Clad Sheet with a layer of 99.7% purity aluminium on both sides. Full particulars of this material are presented in a new leaflet which contains test results for the material at room and elevated temperatures, after soaking at various temperatures.

SINCE its introduction a few years ago, Positive-Grip-Pattern (P-G-P) aluminium treadplate has found application in a variety of fields. Hitherto, it has been available in two patterns only, namely heavy and light. It can now be supplied in small pattern, which is a completely new design complementary to the other patterns, which has been specially devised for such things as kick plates, bulkheads and flooring on passenger transport, and similar applications. A new brochure issued by the makers, The British Aluminium Co., Ltd., gives particulars of the properties and fabrication of this material.

THE principal feature of the Summer, 1957, issue of *Torch*, the publication of British Oxygen Gases, Ltd., is an article on flame cleaning in preparation for painting. Other articles deal with stainless steel welding and the production of railway diesel twin sets. The issue contains the usual brief items dealing with various industrial applications of the company's products.

THE current issue of *Davy-United Engineering* is devoted to articles on two aspects of rolling mill design. In the first, Mr. L. Allen, Gear Engineer, discusses recent

developments in rolling mill gear design and describes present-day methods of manufacture. In the second article, Mr. S. L. Norton, Lubrication Engineer, discusses the developments in lubrication on modern mills, resulting from the demand for faster and more continuous production methods throughout the steel industry.

"NORAL" Industrial Sheet has long been used as a roofing and cladding material for all types of industrial buildings. In recent years it has been widely specified for ships' permanent awnings and sun decks, where it competes on grounds of cost, weight, strength and durability with any of the alternative materials. Northern Aluminium Co., Ltd., have recently issued a 12-page brochure containing technical data, and recommendations for installing Industrial sheet awnings on aluminium, timber and steel frameworks, and illustrated with photographs and line drawings.

AN article in the August 1957 issue of *Evershed News* describes the Venturi pneumatic pyrometer, developed at the British Coal Utilisation Research Association, for measuring gas and flame temperatures. The temperature of the hot gas is computed from the pressure drop of the gas through two restrictors in the probe, and its temperature at the second (cold) restrictor. The instrument is faster in response than other probe instruments (for example, suction pyrometers) and it can be used at higher temperatures.

THE ownership of denationalised steel companies is widely spread. Half the companies have more shareholders than employees. Nine out of ten shareholders own less than 500 shares each, and the ten largest shareholders own together an average of only 11½% of the total capital. These interesting facts emerge from analysis of steel company shareholdings which have been published as a pamphlet by the British Iron and Steel Federation. Copies may be obtained from Steel House, Tothill Street, London, S.W.1.

"DIECASTINGS—YOUR QUESTIONS ANSWERED" is the title of a 24-page booklet recently issued by Fry's Diecastings, Ltd., Brierley Hill Road, Wordsley, Stourbridge. It discusses the relative advantages of pressure and gravity diecasting and details the relative merits of the various non-ferrous alloys which can be diecast. Reference is also made to such topics as complexity and accuracy of the casting, mechanical properties, corrosion resistance, electrical conductivity and surface finish.

SOME industrial processes require very close control of flame characteristics if satisfactory results are to be obtained. The manufacture of electric lamps is a good example, and an account has been published by the Gas Council of equipment installed at the Omega Lamp Works for this purpose. Reprints of the paper are being distributed by George Kent, Ltd., in the hope that they will assist engineers in solving problems arising in installations where a constant air-gas ratio is required. Other recent Kent publications include No. 275, dealing with the Dall tube for flow measurement; No. 283, which gives details of the Kent P orifice fitting for steam-flow measurement; and 1513/957, dealing with door assembly spare parts for Commander instruments.

LABORATORY METHODS

MECHANICAL • CHEMICAL • PHYSICAL • METALLOGRAPHIC
INSTRUMENTS AND MATERIALS

NOVEMBER, 1957.

Vol. LVI, No. 337

The Rapid Analysis of Steelmaking Slags

By S. Muir and A. D. Ambrose

A rapid method of complete solution of steelmaking slags and other silicate materials by fusion in a mixture of sodium carbonate and borax followed by extraction in dilute nitric acid and hydrogen peroxide is described. Details are given of a subsequent spectrographic technique for the analysis of steelmaking slags. The time taken for a single analysis is 35 minutes and the standard deviation is $\pm 3\%$ of the content, or better.

IN the manufacture of steel, a great deal of importance is attached to analytical control of the furnace slag. Samples taken at intervals throughout the process require analysis as quickly as possible in order to prevent loss of production time, but the conventional chemical methods are not adaptable to high-speed working without considerable decrease in accuracy, and, generally, some compromise is adopted whereby results of only moderate accuracy are obtained in about 45 minutes for each sample. With a view to improving both the speed and the accuracy of the analysis, much work has been carried out on spectrographic methods, and a number of papers on the subject have been published, e.g. Refs. 1-9. Broadly speaking, they fall into two categories, viz. those which use the sample as it is received, and those which use some preliminary chemical treatment. The use of an untreated sample has the advantage of speed but, generally, loss of accuracy occurs due to the fact that slag structures vary greatly and may have different excitation characteristics for similar compositions. Preliminary chemical treatment, however, ensures that the sample is always presented for excitation in the same form, and thus a more accurate analysis can be obtained.

A previous publication by the authors¹⁰ outlined a solution method which could be applied to the analysis of a number of materials, including steelmaking slags. Briefly, it consisted of solution of the sample in perchloric acid and removal of silicon by evaporation. The precipitate was filtered off, treated with hydrofluoric acid to remove the silicon, and the residue fused and returned to the main solution. Chromium was added as the internal standard and excitation was by the condensed spark, the solution being absorbed in a graphite electrode. The method is sufficiently accurate for slag analysis where speed is unnecessary, but for routine analysis the time taken is prohibitive. In addition, silica is not determined and a separate chemical analysis is necessary. It was decided, therefore, to attempt some modification whereby the speed of the process would be increased, and, at the same time, the determination of silica included.

The photographic procedure in a spectrographic analysis is fairly lengthy, but it was felt that no further modification could be applied to it without a resulting loss of accuracy. Likewise, evaluation procedures, with

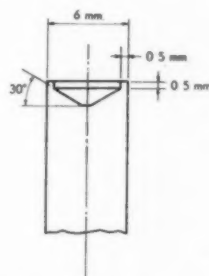
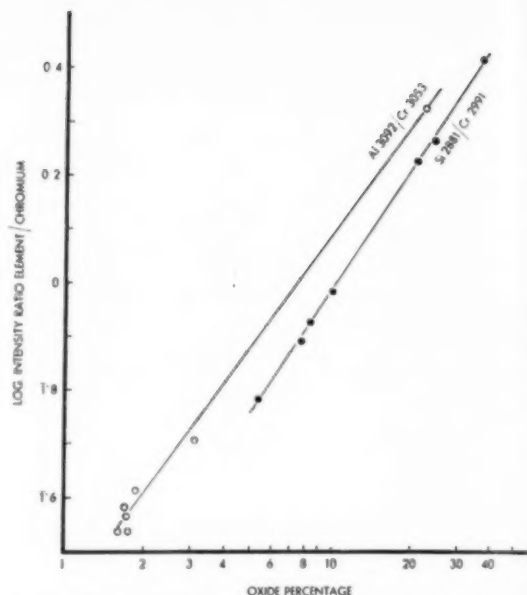
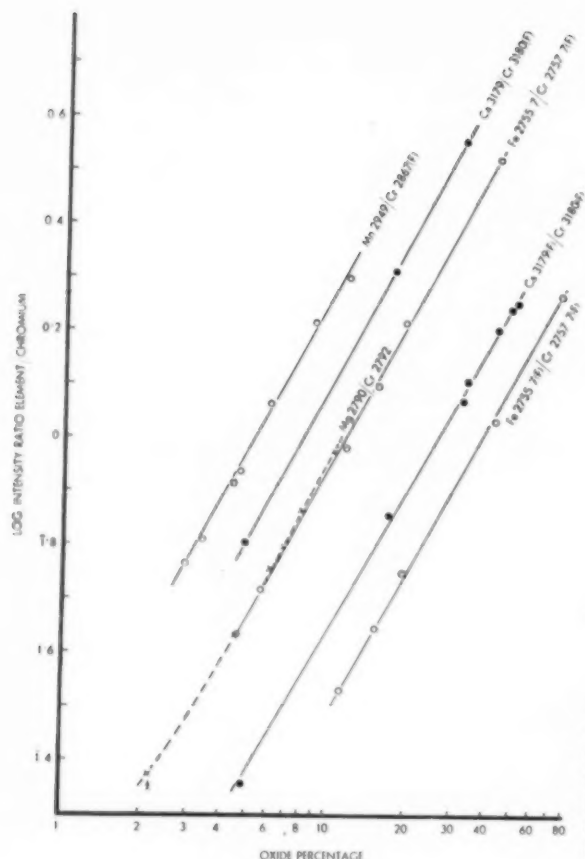


Fig. 1.—Electrode shape for solution analysis.

the help of such aids as graphic calculators, etc., cannot be appreciably shortened. Any modification, therefore, must be in the chemical preparation of the sample.

Fusion of the Sample

The use of various fusion mixtures was first tried with a view to taking samples completely into solution, and it was discovered that fusion with a mixture of sodium carbonate and borax followed by extraction in dilute nitric acid would give a solution of all the elements in slag except manganese. By the addition of sodium nitrite to the solvent, it was found that a complete solution could be obtained. The procedure was fairly simple, except that during the extraction it was necessary to stir the solution continuously in order to prevent local neutralisation of the solution and precipitation of silicon. Later it was found more convenient to use hydrogen peroxide instead of sodium nitrite, since the effervescence produced kept the solution effectively stirred and, in addition, hydrolysis of titanium was prevented. It is thought, too, that hydrogen peroxide may help to prevent hydrolysis of the silicon in the solutions. The length of time during which the solutions remain stable varies considerably, and the authors have been unable to find any explanation for this. Normally solutions remain free from any precipitate for several hours (or, in many cases, weeks), but as a precautionary measure solutions are usually excited immediately after extraction. Since, by this procedure, one can take completely into solution ores, rocks, refractories and other materials containing as much as 90% silica, it is possible that the method can be applied to the analysis of a wide range of materials.



Figs. 2a (left) and 2b (above).—Construction of working curves for the analysis of slags.

Spectrographic Technique

The spectrographic part of the procedure is essentially that previously described by the authors¹⁰, but for the sake of completeness details are given. The electrodes, prepared as shown in Fig. 1, are placed in a closed muffle furnace which is at 900° C., and withdrawn when they reach the temperature of the furnace. This treatment removes the binder from the graphite, leaving a porous mass of hard nodules. It should be emphasised that the appearance of the electrodes should be unaltered after this heat treatment. Over-heating produces a powdery formation on the outside of the electrodes and the solution, when added to the cup, tends to run down far into the electrode, whereas under-heating may prevent the liquid from penetrating into the graphite at all. Electrodes as received from the suppliers vary in porosity from rod to rod, but this heat treatment appears to render them all porous to the same degree.

TABLE I.—CONDITIONS OF EXCITATION OF THE SOLUTIONS

Spectrograph	Large Quarts Littrow type.
Wavelength Range	2800–4000 Å.
Slit Width	0.015 mm.
Source to Slit Distance	35 cm.
Source	A.C. condensed spark (uncontrolled)
Added Inductance	0.015 mH.
Upper Electrode	6 mm. diameter graphite rod, pointed to 80° cone.
Lower Electrode	6 mm. diameter graphite prepared as indicated in the text.
Electrode Gap	2 mm. from the rim of the cup.
Preburn	30 sec. before addition of solution.
Volume of Solution	0.05 ml.
Optical Filter	100%/30% transmission.
Exposure	80 sec.
Photographic Plate	Kodak B.10.

Detailed Procedure

In a mixture of 1 g. anhydrous sodium carbonate and 0.5 g. prefused borax at about 1,100° C., is fused 0.2 g. of sample. The fusion is held molten in the crucible for 4–5 minutes, is then cooled and extracted in 25 ml. 20% (v/v) nitric acid and about 5 ml. hydrogen peroxide solution (100 vols.). After extraction is complete, the crucible is removed and 10ml. standard potassium or sodium dichromate solution are added (1 ml. 0.025 g. Cr). The volume is now adjusted to about 50 ml. and the solution is ready for excitation under the conditions shown in Table I.

Evaluation of Spectra

Since it is extremely difficult to prepare standards synthetically when silica is to be included, a series of

TABLE II.—SPECTRUM LINE PAIRS USED IN THE ANALYSIS

Element Line	Total Excitation Potential	Reference Line	Total Excitation Potential	Index Value %
Si I 2881.5	5.1	Cr I 2991.8	5.1	11
Mg II 2790.8	16.4	Cr II 2792.2*	15.3	3
Mg II 2790.8	16.4	Cr II 2792.2	15.3	10
Fe II 2755.7*	13.3	Cr II 2757.7*	12.6	39
Fe II 2755.7	13.3	Cr II 2757.7*	12.6	11
Al I 3092.7	4.0	Cr I 3053.9	5.0	7.5
Mn II 2949.2	12.8	Cr II 2867.6*	12.5	5
Mn II 2949.2	12.8	Cr II 2867.6	12.5	16.5
Ca II 3179.3*	13.1	Cr II 3180.7*	13.1	27
Ca II 3706.0	12.5	Cr II 3421.3*	12.8	30
Ca II 3706.0	12.5	Cr II 3422.9*	12.8	38

* Filtered spectrum.

Typical working curves are shown in Fig. 2.

TABLE III.—REPRODUCIBILITY TEST OF THE METHOD

Constituent	Standard Deviation (as percentage of content)	Approximate Content (%)
SiO ₂	3.0	25
CaO	1.7	44
MnO	1.9	6
MgO	1.8	10
FeO	2.1	5.5
Al ₂ O ₃	3.2	3

chemically analysed samples are used in the preparation of working curves. It is recommended that such a series should be analysed in several laboratories so that chemical errors may be kept to a minimum.

It has been shown previously¹⁰ that in solution spectrographic analysis it is essential to use line pairs which are homologous, or nearly so, and Table II is a list of line pairs suitable for the analysis of slag. For plate calibration, the iron line series method is used, microphotometer readings being converted to P-transformation values¹¹.

Accuracy and Speed of the Method

A number of reproducibility tests have indicated a standard deviation of 3% of the content, or better, for the principal constituents in slag samples. Results of a typical test are shown in Table III. A comparison of spectrographic and chemical analyses of a number of slags and slag-like materials is made in Table IV. All the spectrographic results shown are single determinations.

The preparation of a sample solution for analysis can be carried out in 10 minutes. This means that an analysis can be completed in about 35 minutes, which compares favourably with chemical procedures, especially when one considers that the complete analysis is available when required. However, it is suggested this is not yet as rapid as furnace operators desire. Since most of the time of an analysis is taken up by photographic processing and evaluation, it can reasonably be assumed that with the use of a direct-reading spectrograph, a reduction of speed to about 15 minutes should be possible. This would then meet the requirements of furnacemen. It is hoped, therefore, that tests may be carried out in the near future on such an instrument.

Acknowledgments

The authors wish to thank the Director of Research of Messrs. Stewarts and Lloyds, Ltd., for permission to publish this work, and Mr. T. H. Williams for his help and encouragement.

TABLE IV.—COMPARISON OF CHEMICAL AND SPECTROGRAPHIC ANALYSES

Sample	Method	SiO ₂	CaO	Fe	MgO	MnO	Al ₂ O ₃
Bessemer Slag	Spectrographic	7.4	54.0	9.5	1.05	2.9	—
	Chemical	7.5	53.7	10.3	1.10	2.9	—
Open Hearth Slag	Spectrographic	9.0	46.9	13.5	8.8	5.0	1.80
	Chemical	9.9	46.5	13.5	8.7	5.2	1.59
Open Hearth Slag	Spectrographic	16.5	44.0	8.0	6.0	3.2	—
	Chemical	16.2	44.7	8.9	6.9	3.3	—
Open Hearth Slag	Spectrographic	17.0	47.9	5.5	6.0	6.0	2.4
	Chemical	16.4	47.3	5.4	5.7	7.0	2.0
Open Hearth Slag	Spectrographic	61.5	9.2	8.8	—	14.2	3.3
	Chemical	60.8	9.0	8.5	—	13.8	3.5
Electric Furnace Slag	Spectrographic	11.1	42.7	19.6	9.4	7.3	3.0
	Chemical	10.8	41.5	19.0	9.1	7.2	2.9
Blast Furnace Slag	Spectrographic	33.1	39.8	0.43	2.2	1.43	20.5
	Chemical	33.1	40.0	0.48	2.3	1.15	19.9
Blast Furnace Slag	Spectrographic	30.9	42.4	0.39	2.5	1.82	19.0
	Chemical	30.9	42.8	0.30	2.6	1.70	18.5
Blast Furnace Slag	Spectrographic	32.2	36.0	—	5.9	—	19.0
	Chemical	33.0	36.0	—	5.9	—	19.5
Slater	Spectrographic	13.5	9.8	45.1	1.75	—	6.6
	Chemical	13.5	9.8	45.4	1.79	—	6.9
Bassett Fork	Spectrographic	45.3	—	8.2	9.7	—	14.0
	Chemical	45.0	—	8.6	9.8	—	13.2

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British Oxygen Linde Orders

A RECENT review of contracts placed in the past few months for tonnage oxygen plants reveals interesting details of the activities of British Oxygen Linde which has received export orders for tonnage oxygen/nitrogen installations worth over £2½ million. Other orders received by the Company in this keenly competitive field, include two installations in the United Kingdom for the Shell Group of Companies, which are due for completion early in 1958.

Two of the recent orders are for tonnage plants to serve the Indian iron and steel works being built at Durgapur and Rourkela, each of one million ingot tons a year capacity. The largest is for the German-built steel works at Rourkela, where steelmaking is based on the oxygen-steel process. The British Oxygen Linde plant will comprise three units each producing 100-tons/day of oxygen of a purity of 99.5%. At Durgapur, where the British-built steel works is based essentially on the open-hearth process, oxygen requirements will be lower, and the plant will comprise two units each of 50-tons/day capacity.

In accordance with the Indian Government policy to install fertiliser plants alongside new integrated iron and steel works, to utilise the hydrogen from the coke oven gas and the nitrogen from the tonnage plants, both installations are required to produce pure nitrogen also. At Rourkela, only a relatively small proportion of the total available nitrogen will be required, and the plant will be designed on the Linde-Frankl (low pressure) principle, whereby the air is cooled by heat exchange in regenerators. This design is particularly suitable and economical for the production of the requisite quantities of oxygen and nitrogen. The plant at Durgapur will operate on the medium pressure principle, under which the air is compressed initially to about 11 atmospheres (compared with 5-6 atmospheres in the Linde-Frankl process), and is purified chemically. The heat exchangers are of the conventional indirect contact type. This process is more suited to the smaller scale of production and the relatively higher yield of nitrogen required at Durgapur. In each case sufficient pure nitrogen will be available for the manufacture of several hundred thousand tons/year of concentrated fertilisers.

A further order, worth some £800,000, is for a plant with a combined daily output of 275-tons of oxygen and 285-tons of nitrogen to be erected at Modderfontein for African Explosives and Chemical Industries, Ltd. It is to be used to extend capacity for producing ammonia by the synthesis process, involving the use of oxygen gasification for hydrogen production.

Of the two home orders nearing completion, that at Shell Haven is to supply oxygen and nitrogen for ammonia manufacture. The other, for Petro-Chemicals, Ltd., at Partington, will also supply both gases, the oxygen to be used for the direct oxidation of ethylene.

Items of Metallurgical Interest at Recent Instrument Exhibitions

The recent Instruments, Electronics and Automation Exhibition at Olympia aroused considerable interest, as might be expected at a time when automatic devices are finding increasing application in industry and commerce. In this series of articles, reference is made to items of metallurgical interest exhibited at Olympia, and at the Physical Society Exhibition which, as usual, provided an opportunity for the display of new commercially available and prototype instruments and laboratory equipment.

Scratch Investigation Microscope

THERE are many industrial processes where it is necessary to measure the depth of irregularities, such as scratches, blisters, pitting or general roughness in a fairly coarse surface. This type of surface is too rough to examine with an interference microscope, and more information is often required about superficial structure over an area than can be given by a stylus instrument. The scratch investigation microscope shown by Hilger & Watts, Ltd., was developed to serve this purpose, and is based on the fact that the shadow of a straight line which falls obliquely on a stepped surface shows irregularities which correspond with the surface contour.

This instrument throws an oblique shadow of the edge of a graticule on to the surface under examination, and the amount of indentation in the edge of the shadow is read on a graticule in the eyepiece after magnification by a low power microscope. The microscope, which is provided with three feet so that it stands firmly on flat or curved surfaces, is placed so that the sharp edge of the shadow is at right angles to the scratch under examination. The edge of the shadow is sharply in focus when the surface itself is in focus, and a scale is provided in the field of view from which the depth of the indentation can be read off directly in thousandths of an inch.



Hilger & Watts scratch investigation microscope with camera in position.

Another scale, perpendicular to the first enables the width of the scratch to be measured at the same time.

A camera unit has been designed which can be attached to the scratch investigation microscope for the purpose of making photographic records on 35 mm. roll film. The camera can be attached to the eyepiece of the microscope by means of a special bayonet adaptor. After focusing the microscope on the scratch which is to be examined, the camera is attached to the eyepiece and the eyepiece graticule is viewed through the camera periscope, which is designed to inspect the centre of the field of view. The scratch will then also be in focus. It is possible to re-focus on other objects without detaching the camera from the microscope. The periscope is automatically withdrawn when the button (or trigger release) is depressed to expose the film. The film cassette holds 36 exposures, but fewer can be taken and cut off as required. The camera has safety interlocking devices so that exposures cannot be made until the film is wound into the next position.

Inverted Metallurgical Microscope

The M29 series metallurgical microscope shown by Cooke, Troughton & Simms, Ltd., is intended for routine examination of materials. Of the inverted type, it has self-contained illumination, quintuple objective changer, and a gliding-type stage. The illuminating unit, situated in the base of the instrument, consists of a 6 volt, 15 watt, pre-focused lamp, a condensing system, an iris with centring adjustment, and provision for inserting filters. On the microscope body is a field iris which can be focused and centred, the whole providing means for the Kohler principle of illumination. Current for the lamp is supplied by a variable transformer.

Any of the five objectives can be brought on to the optical axis without altering the vertical height of the stage. The focusing mechanism is contained within a casing which serves as a column for supporting both the microscope and the stage limit. Coarse and fine motions are arranged concentrically, the former operating the stage limb and the latter, which is of ball-bearing construction, the microscope.

The object stage is of the gliding type, and is carried on a circular platform attached to the limb. A film of grease which separates the elements enables the upper one to be moved with great precision without the aid of any mechanical means.

The microscope is manufactured in binocular and monocular forms, and a single frame camera is available for single exposures on 35 mm. film. The camera can be supplied in two forms, one fitting directly into the

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Micro-Hardness Testing

This article describes experiences and results obtained over five years of using the micro-hardness testing technique, both from the laboratory point of view and as a production quality control method. It is based on a lecture delivered to the Engineering Metrology Association at the Northampton College of Advanced Technology by Mr. R. Wall, M.B.E., Metallurgist, Associated Automation, Ltd., makers of the G.K.N. micro-hardness tester.

DURING the past twenty years, the development and production of an increasing number of small compact electro-mechanical and electronic devices—such as adding machines, computers, clocks, motors, gears and gyros—has depended on the manufacture to close limits of large numbers of small parts in most of the conventional engineering materials. The failure of even one small part due to wear caused by incorrect hardness is a serious and worrying problem.

Hardness testing of the macro-type is widely used throughout industry, no test room being complete without an instrument for this purpose. Machines of the Vickers, Brinell, Rockwell and Scleroscope types are available to cover this field, and within the ranges for which they were designed and developed they are quite satisfactory. They are not suitable, however, for testing thin metal foil, fine wire, small springs, electro-deposited metal, small pivots, thin cyanided or nitrided case hardened steel parts, etc., as the heavy loading of the indenter would cause penetration and distortion.

Typical Instrument

From the laboratory development of low-load or micro-hardness testing came the instrument which supplements the conventional hardness testing machines. The micro-hardness tester, designed for use at very low loads, is a delicate instrument requiring a high degree of accuracy and a reasonable amount of handling skill. In principle, most micro-hardness testers are similar in design to the standard Vickers hardness tester, but on a smaller scale. A typical instrument comprises the following:—

- (1) A hardness testing unit with a delicately balanced beam carrying a Vickers type diamond indenter of 136° included angles. It has provision for high and low power objectives and an indenting position, accurately indexed by a turret method, and for centring objectives a means of accurate and rigid attachment to a microscope system is also provided.
- (2) A mechanical stage with micrometer adjustment for accurately locating the specimen under the hardness tester.
- (3) A suitable metallurgical microscope, fitted with an adjustable draw-tube to take a Filar micrometer eyepiece. Magnifications of the order of $\times 50$ or $\times 100$ are commonly used in measuring micro-hardness indentations.
- (4) An instrument panel or box to indicate accurately the point of load application.
- (5) A range of accurately calibrated weights. Depending on the type of instrument, these could be 1, 3, 10, 30, 100, 200 and upwards to, say, 500g.

- (6) A British Standard table of hardness numbers, from which ocular measurement of the diamond impression will evaluate a hardness number dependent on the applied load at the diamond point.

Testing Procedure

A micro-hardness test is made by pressing a square diamond pyramid (136° included angle between opposite faces) into the specimen with an accurate load of, say, 500g. or less. The Knoop diamond indenter which is also used on some micro-hardness testers, is an elongated pyramid having angles between the long and short edges of $172^\circ 30'$ and 130° , respectively. These indenters are more difficult to produce, and errors in angle are more serious than with the normal Vickers indenter.

To obtain reliable results in micro-hardness testing, care in mounting the specimen is essential. The following points should be noted in this respect.

- (1) The surface to be tested must be suitably prepared and the correct load chosen: the highest permissible load should be used.
- (2) Specimens may be mounted using plasticine or fast drying cements, or with suitable small clamps or metallurgical mountings.
- (3) A good micro-finish is necessary for laboratory testing and examination. For routine sample-batch production testing, polishing to approximately 6 micro-in. by means of 4/0 polishing paper is satisfactory. Electrolytic polishing of some materials for laboratory examination is also useful.
- (4) After the impression has been made, the method of measuring it is important. At least three impressions should be made and the average of the six diagonals taken.

Production Control

Micro hardness testing can be used for metallurgical and production quality control, and in the author's company a series of small precision clamps of various sizes are used for mounting small parts. Plasticine mounting is sometimes used, and where the size and shape are suitable, ferrous parts are held in position by a small surface magnet. The techniques developed aim at the polishing, mounting and testing of small parts in 10–15 min. Among the components tested are small hardened springs, case hardened parts with shallow depths of case, small tools, ball bearing pivots, electroplated parts coated with nickel, chromium, rhodium, silver and copper, and thin steel strip.

For the testing of steel wire of 0.006 in. diameter and upwards, a special clamp is prepared to take twelve samples. One sample is taken from each reel, the cross-

sections polished in the clamp, and a hardness test made on each. The wire is then graded by its hardness number, which is marked on the reel. This grading is then related to the setting-up tension on the machine used for the production of a particular batch of springs, and the trial-and-error period otherwise necessary is eliminated. Wire of the same section from two manufacturers—and occasionally from the same supplier—may show differences in micro-hardness figures from 540 to 670 V.P.N. at a 100g. load. It can be seen that this difference in hardness would show a proportional difference in springs produced under the same manufacturing conditions to the same specification.

Batch samples from production should be micro-hardness tested and the results recorded. In this way an indication will be obtained of the reproducibility of hardness of a given material after a specific heat treatment. Where a normal Vickers diamond pyramid hardness tester is available, its test block should be polished to the standard necessary for micro-hardness testing, and the micro-hardness figure referred to the Vickers hardness figure of the certified block at 5, 10 and 30 kg.

Experience shows that on a suitably prepared chromium steel test block, hardness figures of 321–326 V.P.N. at 30kg. have a reproducibility on a micro-hardness tester of 318–330 V.P.N. at 100g. and 30g. loadings, measurement being made at $\times 500$. Production parts checked by the micro-hardness method have been cross-checked by the Vickers test when practicable, and show a fair practical agreement between the two methods.

In some cases, tool steels, high speed steels, carbon-chrome steels and cyanide hardened steels, hardened and tempered to give a Vickers hardness figure in the range 700–880 V.P.N. have a micro-hardness value some 40–60 points higher when correctly prepared. Steels, copper and its alloys, and aluminium and its alloys show satisfactory agreement at 100g. and 30g. loads in the range 100–450 V.P.N.

Sources of Error

Some of the main sources of error in micro-hardness testing are set out below:—

- (1) Poor preparation of the specimen.
- (2) Vibration of the micro-hardness tester.
- (3) Carelessness in measuring the impression.
- (4) Inexperienced operator.
- (5) Equipment out of adjustment.
- (6) Incorrect magnification used.
- (7) Material under test having a multi-phase structure with hardness differences between phases.
- (8) Failure to interpret the metallurgical condition of the surface of the specimen. Errors may arise due to decarburisation, the presence of retained austenite, or the presence of a work-hardened layer.

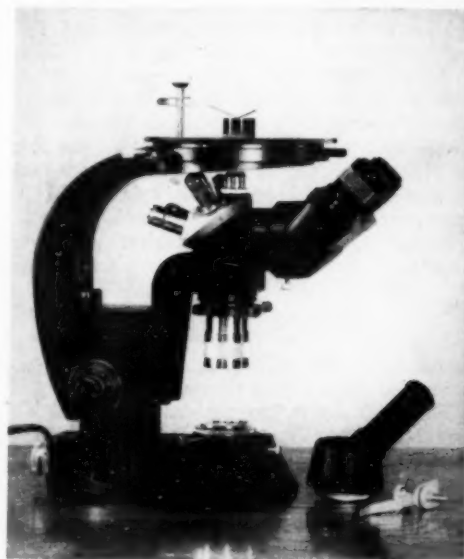
An example of the discrepancy in hardness figures which can arise as a result of the surface condition of the specimen is provided by a 0.014 in. thick hard chromium deposit, surface ground for service, which was reported soft. On investigation, micro-hardness tests at a 100g. load gave a figure of 650 V.P.N., whereas a 5kg. Vickers test gave 920 V.P.N. Further examinations revealed

that the chromium deposit had been ground dry at too high a cutting speed, and a temperature of over 300°C. had been reached. This tempered the surface skin to a depth of approximately 9 microns.

A useful report, issued by the Hardness Testing Committee of the Institute of Sheet Metal Engineering, on a study of the standard of hardness testing in industry refers to the difference in hardness values obtained by various establishments on standard specimens. Using the same type of equipment, a scatter of as much as 200 V.P.N. was noted in the 700–900 V.P.N. range. Errors of this magnitude on the macro-scale, resulting from incorrect selection of load and poor surface preparation, would result in much greater errors when micro-hardness testing under the same unsatisfactory conditions.

Instrument Exhibits

(Continued from page 258).



Cooke, Troughton & Simms inverted metallurgical microscope.

monocular tube, and the other comprising the same film holder assembly arranged to screw directly on to a 35 mm. $\frac{1}{2}$ \times projector tube, with shutter and with or without a viewing eyepiece. The attachment fits over the monocular tube with an eyepiece in place.

New Instrument Venture

THE official opening of the new factory of Optica United Kingdom, Ltd., at Team Valley Trading Estate, Gateshead-on-Tyne took place recently in the presence of Mr. H. Bueckert, Chairman of Optica s.p.a. of Milan, Italy, and Mrs. Bueckert. The new company, which is a joint venture between Optica, Milan, and Joyce, Loeb and Co., Ltd., Newcastle upon Tyne, is producing recording U.V. spectrophotometers, direct-reading spectrographs and other spectrographic and industrial instruments and automatic controls.

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